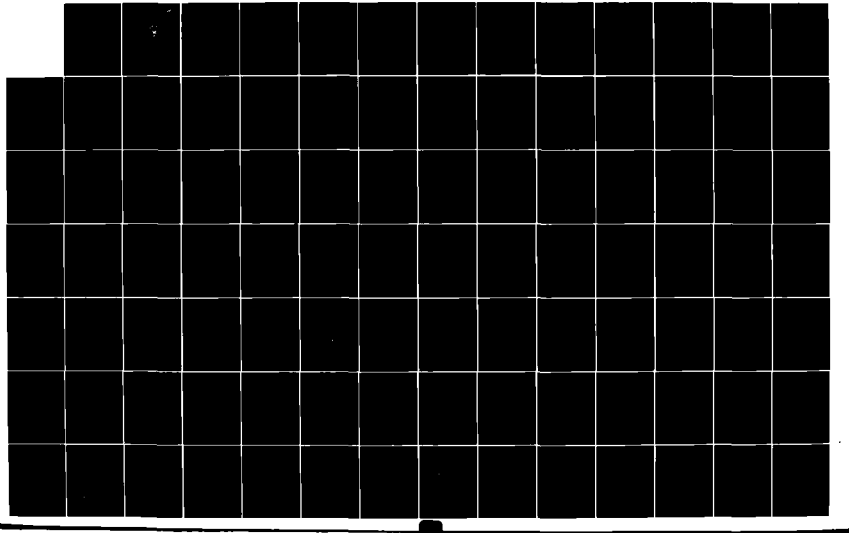
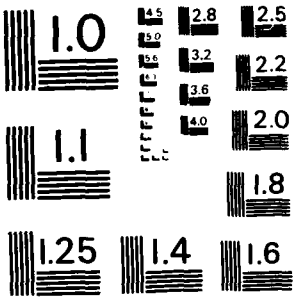
AD-A132 414 PRELIMINARY PROPELLER SELECTION USING THE WAGENINGEN B-SCREW SERIES AND A GENERAL PURPOSE NON-LINEAR OPTIMIZER(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA M P SMITH JUN 83 F/G 13/10 NL

1/4

UNCLASSIFIED





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

AD-A132414

NAVAL POSTGRADUATE SCHOOL
Monterey, California



DTIC
ELECTE
SEP 15 1983
D

THESIS

PRELIMINARY PROPELLER SELECTION USING THE WAGENINGEN B-SCREW SERIES AND A GENERAL PURPOSE NON-LINEAR OPTIMIZER

by

Michael Peter Smith II

June 1983

Thesis Advisors: D. Salinas
G. N. Vanderplaats

Approved for public release; distribution unlimited.

DTIC FILE COPY

83 09 14 060

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. A132 414	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Preliminary Propeller Selection Using the Wageningen B-Screw Series and a General Purpose Non-Linear Optimizer	5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; June 1983
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Michael Peter Smith II	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	12. REPORT DATE June 1983
	13. NUMBER OF PAGES 362
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)	
18. SUPPLEMENTARY NOTES	
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Wageningen propeller propeller strength propeller selection ship powering FORTRAN design optimization	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This thesis presents the use of a general purpose non-linear optimization program in the preliminary stage of ship design for the selection of a propeller based on methodical series propeller test data. The propeller series utilized is the well-known Wageningen B-Series. Three (3) "Design Cases", representing the thrust, power and matching approaches to powering problems, are formulated as FORTRAN subprogram analysis codes for solution by	

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(20. ABSTRACT Continued)

the synthesis/optimization program COPES/CONMIN. Designer constraints considered are:

1) diameter limitation
2) cavitation limit on expanded area ratio using Keller's criterion
3) strength requirement determined by an empirical relation and by a method developed by Schoenherr with modifications by the author.

Objective functions considered are maximized open water efficiency and minimized propeller blade weight. Optimized solutions to specific problems previously presented by other authors are obtained and results are compared.

Accession For
NTIS GRA&I ☒
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A

Approved for public release; distribution unlimited.

Preliminary Propeller Selection Using the Wageningen B-Screw Series and a General Purpose Non-Linear Optimizer

by

Michael Peter Smith II
Lieutenant, United States Naval Reserve
B.S., St. John Fisher College, 1971
B.S.E., The University of Michigan, 1976

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

June 1983

Author: Michael P Smith II

Approved by: Garth N. VanLeuvenhaut
Thesis Advisor

David Salinas
Thesis Advisor

R. J. Marto
Chairman, Department of Mechanical Engineering

J. D. Dyer
Dean of Science and Engineering

ABSTRACT

This thesis presents the use of a general purpose non-linear optimization program in the preliminary stage of ship design for the selection of a propeller based on methodical series propeller test data. The propeller series utilized is the well-known Wageningen B-Series. Three (3) "Design Cases", representing the thrust, power and matching approaches to powering problems, are formulated as FORTRAN subprogram analysis codes for solution by the synthesis/optimization program COPES/CONMIN. Designer constraints considered are:

1) diameter limitation,
2) cavitation limit on expanded area ratio using Keller's criterion,
3) strength requirement determined by an empirical relation and by a method developed by Schoenherr with modifications by the author.

Objective functions considered are maximized open water efficiency and minimized propeller blade weight. Optimized solutions to specific problems previously presented by other authors are obtained and results are compared.

TABLE OF CONTENTS

I. INTRODUCTION ---------- 14

A. BACKGROUND ---------- 14

B. PROBLEM STATEMENT ---------- 19

C. SCOPE ---------- 19

D. THESIS ORGANIZATION ---------- 19

II. OPTIMIZATION ---------- 22

A. INTRODUCTION ---------- 22

B. DEFINITIONS ---------- 22

C. PROBLEM STATEMENT ---------- 25

D. COPES/CONMIN ---------- 28

1. CONMIN ---------- 28

2. COPES ---------- 30

E. CONCLUDING NOTE ---------- 32

III. POWERING, PERFORMANCE AND PROPELLERS ---------- 33

A. INTRODUCTION ---------- 33

B. DEFINITIONS ---------- 33

C. POWERING CONCEPTS ---------- 37

1. Basic Relations ---------- 37

2. Approaches to the Powering Problem ------ 38

D. PROPELLER PERFORMANCE CHARACTERISTICS ------- 40

E. THE WAGENINGEN B-SCREW SERIES ---------- 44

1. Background ---------- 44

2. Series Results ---------- 45

3. Limitations on Series Data ---------- 48

F. SUMMARY ---------- 50

IV. PROPELLER SELECTION--AN OPTIMIZATION PROBLEM ---- 52

A. INTRODUCTION ---------- 52

B. DESIGNER'S CONSIDERATIONS ---------- 52

1. Propeller Size ---------- 52

2. Cavitation ---------- 53

3. Strength ---------- 54

C. THE DESIGN VECTOR ---------- 56

1. Parameters ---------- 57

2. Design Variables ---------- 58

D. CONSTRAINTS ---------- 60

E. OBJECTIVE FUNCTIONS ---------- 61

F. PROPELLER SELECTION OPTIMIZATION PROBLEM STATEMENT ---------- 62

G. CODING FUNDAMENTALS ---------- 62

1. GLOBCM Common Block ---------- 62

2. SUBROUTINE ANALIZ ---------- 62

H. SUMMARY ---------- 65

V. PROPELLER BLADE WEIGHT--AN OBJECTIVE FUNCTION --- 67

A. INTRODUCTION ---------- 67

B. THEORY AND PROCEDURE ---------- 67

1. Limits of Integration ---------- 67

2. Blade Section Profile ---------- 69

3. Blade Section Cross-Sectional Area ------ 71

4. Volume Integration ---------- 72

5. Blade Weight ---------- 72

C. CODING ---------- 72

D. SUMMARY ---------- 73

VI. THICKNESS-TO-CHORD RATIO--A DESIGN CONSTRAINT --- 74

A. INTRODUCTION ---------- 74

B. PROPELLER STRENGTH ANALYSIS--A HISTORICAL REVIEW ---------- 74

C. SCHOENHERR'S METHOD ---------- 79

1. Background ---------- 79

2. The Blade Model ---------- 80

3. Bending Moments Due to Hydrodynamic Loading ---------- 82

4. Force and Bending Moments Due to Centrifugal Loading ---------- 85

D. ALGORITHM FOR THE CONSTRAINT ---------- 97

1. Theory ---------- 97

2. Coding Details ---------- 99

E. SUMMARY ---------- 100

VII. DESIGN CASE NO. 1--PROGRAMMING AND COMPARISONS -- 101

A. INTRODUCTION ---------- 101

B. THRUST APPROACH FORMULATION ---------- 101

1. Design Vector $\overline{XI}$ ---------- 101

2. Powering Constraint ---------- 103

C. PREVIOUS SOLUTIONS ---------- 104

D. SOLUTIONS BY COPES/CONMIN ---------- 106

1. Variation 1 ---------- 107

2. Variation 2 ---------- 109

3. Variation 3 ---------- 109

4. Variation 4 ---------- 111

E. DISCUSSION ---------- 111

VIII. DESIGN CASE NO. 2--PROGRAMMING AND COMPARISONS -- 114
A. INTRODUCTION ---------- 114
B. POWER APPROACH FORMULATION ---------- 114
1. Design Vector $\overline{X2}$ ---------- 114
2. Powering Constraint ---------- 116
C. PREVIOUS SOLUTIONS ---------- 117
D. SOLUTIONS BY COPES/CONMIN ---------- 119
1. Variation 1 ---------- 120
2. Variation 2 ---------- 122
3. Variation 3 ---------- 123
4. Variation 4 ---------- 124
E. DISCUSSION ---------- 124
IX. DESIGN CASE NO. 3--PROGRAMMING AND COMPARISONS -- 128
A. *INTRODUCTION* ---------- 128
B. "MATCHING" FORMULATION ---------- 128
1. Design Vector $\overline{X3}$ ---------- 128
2. Powering Constraint(s) ---------- 129
C. PREVIOUS SOLUTIONS ---------- 131
D. SOLUTIONS BY COPES/CONMIN ---------- 133
1. Programming Details ---------- 135
2. Results ---------- 135
E. DISCUSSION ---------- 136
X. CONCLUSIONS AND RECOMMENDATIONS ---------- 139
A. CONCLUSIONS ---------- 139
B. RECOMMENDATIONS ---------- 141
C. A FINAL NOTE ---------- 142

APPENDIX A: FORTRAN VARIABLE CROSS REFERENCE LIST ---- 143

APPENDIX B: SUBROUTINE LISTINGS ---------- 145

APPENDIX C: ANALIZ CODES--DESIGN CASE NO. 1 ---------- 215

APPENDIX D: CONTROL CARD IMAGES--DESIGN CASE NO. 1 --- 231

APPENDIX E: COPES OUTPUT--DESIGN CASE NO. 1 ---------- 234

APPENDIX F: ANALIZ CODES--DESIGN CASE NO. 2 ---------- 272

APPENDIX G: CONTROL CARD IMAGES--DESIGN CASE NO. 2 --- 288

APPENDIX H: COPES OUTPUT--DESIGN CASE NO. 2 ---------- 291

APPENDIX I: ANALIZ CODES--DESIGN CASE NO. 3 ---------- 330

APPENDIX J: CONTROL CARD IMAGES--DESIGN CASE NO. 3 --- 334

APPENDIX K: COPES OUTPUT--DESIGN CASE NO. 3 ---------- 336

LIST OF REFERENCES ---------- 356

INITIAL DISTRIBUTION LIST ---------- 360

LIST OF TABLES

I. Summary of the Wageningen B-Screw Series -------- 45

II. Material Identifier Reference ------------------- 58

III. Global Common (GLOBCM) Catalog ----------------- 63

IV. Design Case No. 1--Results ---------------------- 113

V. Design Case No. 2--Results ---------------------- 127

VI. Design Case No. 3--Results ---------------------- 138

LIST OF FIGURES

1.1	Traditional Design Spiral	15
3.1	Open Water Test Results--B 4-100 Series Propeller	42
4.1	Design Vectors $\overline{D}$ and $\overline{X}$	59
5.1	Propeller Blade & Hub--Side View	68
5.2	Expanded Cylindrical Blade Section--Profile View	70
6.1	Strength Section at $r = r_o$	83
6.2	Bending Moments due to Thrust and Torque	86
6.3	Center of gravity "G" and intersection point "N"	88
6.4	Internal Loading on a Blade Section at $x = x_o = r_o/R$	89
6.5	Position of "g" of a Blade Section "Slice" at $x = r/R$	93
6.6	Coordinates of centroid "g" of any Blade Section	94

ACKNOWLEDGEMENTS

It has been said:

> If someone says it's impossible, then, quite obviously, he has never done it.

With these words in mind, I now recall and give thanks to those who have assisted me in attaining the educational goal represented by this thesis:

My mother and father, who provided, among other things, a secure and stable home for me to grow up in and who always insisted that I fulfill my potential for formal education at every opportunity.

My brothers and sister, who have always offered me nothing but praise and encouragement in all of the tasks that I have ever set out to do.

My aunts and uncles, living and deceased, who provided the counseling or the little "envelope for a rainy day" when I needed it the most.

My grandparents, now deceased, who possessed the courage and forethought to venture forth across an ocean to our great country in order to build a better life for themselves and to afford their offspring opportunities of a lifetime.

My close friends, past teachers, instructors and professors, who always pointed me in the right direction with astute guidance and timely advice when all seemed lost.

That one junior Naval officer, who was not afforded the opportunity to achieve the milestone represented by this

work because he maintained "the watch" for a shipmate like me.

And, finally, to You.

On a more current and professional note, I especially thank Dr. Marto, Professor Salinas, Professor Vanderplaats and also LCDR Michael R. Maixner, USN. Their patience, understanding and tireless efforts in helping me close out my academic career on a successful note are deeply appreciated and will always be remembered.

And a special word of thanks to Mr. Robert Lande for the expeditious and accurate typing of this thesis.

I. INTRODUCTION

A. BACKGROUND

The ship design process, in its most rudimentary form, has been formulated and tracked by the utilization of the classical design spiral (see Figure 1.1). The design follows a convergent helical path past each major milestone "spoke" until, after numerous iterative cycles, the final configuration is "centered" upon. Whether one attempts to segregate the principal phases of Preliminary, Advanced and Contract Design into separate spirals or combine these phases in series along the entire path to the center, it is not long before the designer's roughed-out sketches give way to serious "number crunching", specifically that of propulsion power estimation.

To estimate the power required to drive the ship through the water at its design speed, a decision must first be made as to what type of propulsor (i.e., propeller, water jet, paddle wheel, etc.) will be used. For the average case, and for the discussion that follows, the marine propeller is chosen to be the propulsion device. Since

> a ship propeller may be regarded as a transducer that converts the rotational power transmitted through the shaft into the translational power to propel the ship, [Ref. 18: p. 10]

the selection and design of this device is obviously an important factor in the eventual size (weight and power) of the ship's propulsion plant. While hydrodynamicists provide

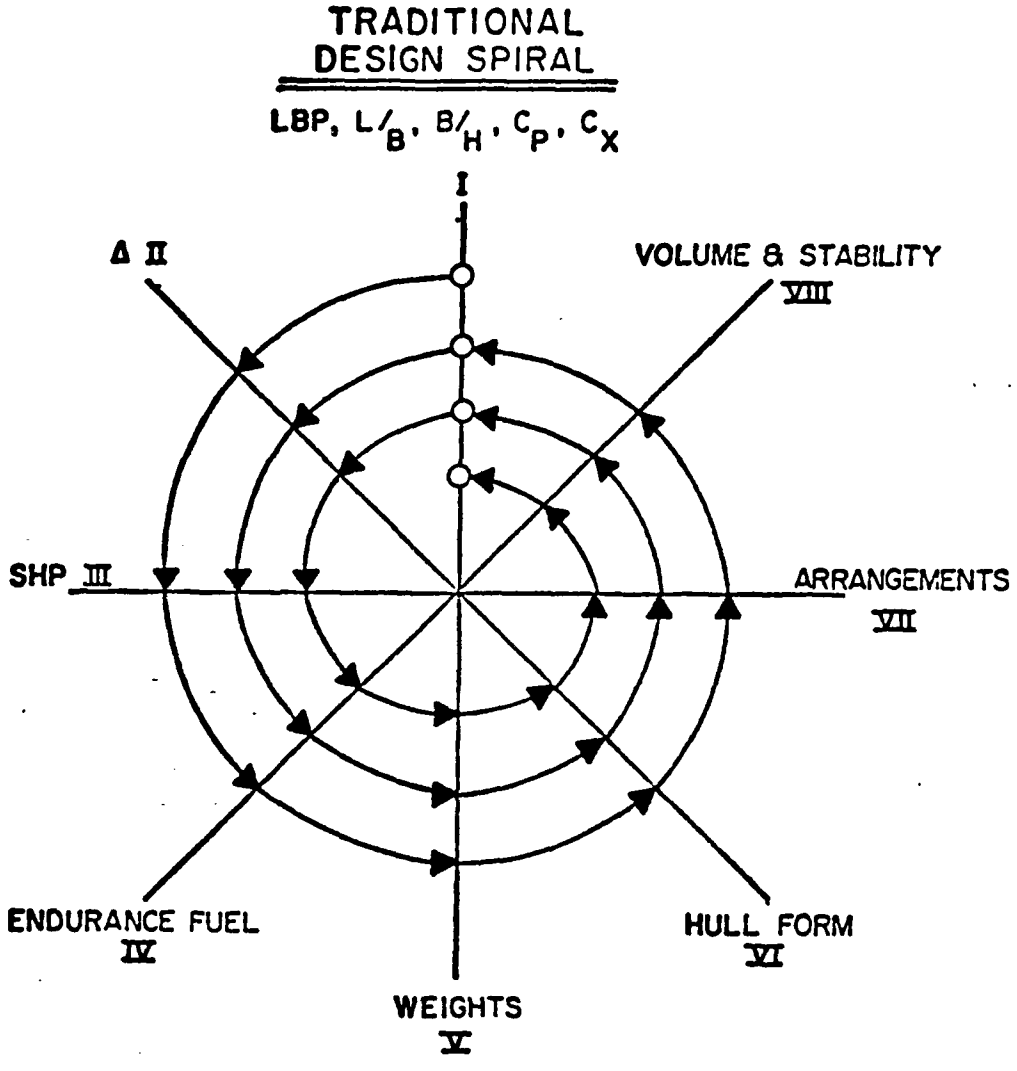


Figure 1.1 Traditional Design Spiral

a myriad of theories and techniques to generate a "custom built" (i.e., wake adapted) propeller for the ship under consideration, their expertise is usually not required in the early stages of preliminary design simply because the design has not been refined enough beyond gross estimates. At this stage, the designer strives to formulate what is possible based on previous experience. For preliminary power estimation, previous propeller designs (i.e., "stock" propellers) and results from methodical series of model propellers are analyzed by the designer in order to select the "best" available propeller under various conditions posed by the problem under consideration. Three examples of typical problems encountered in preliminary ship design are:

1) Given the ship's effective horsepower at a specific speed and estimates of hull performance parameters, which propeller, as determined by certain principal characteristics, will require the least amount of delivered power from the propulsion plant?

2) Given the delivered power from a specific propulsion system in terms of torque and revolution rate at the propeller/shaft interface and estimates of hull performance parameters, which propeller will generate the largest effective horsepower and speed parameters?

3) Given a ship's effective horsepower and speed, various hull performance parameters, and the propulsion plant's delivered power characteristics, which propeller will "match"

these requirements at a minimum amount of weight for a specified material?

(Author's Note: For the sake of brevity, the three selection problems just cited will, henceforth, be referred to as "Design Case No. 1", "Design Case No. 2" and "Design Case No. 3", respectively.)

For this study, the methodical propeller series method is viewed as the designer's choice for preliminary powering analysis. One of the most-widely used methodical series data on model propellers is the Wageningen B-Screw Series. Initially, the results of the series were presented as tabulations of non-dimensional thrust and torque coefficients (K_T and K_Q respectively) versus the non-dimensional advance ratio (J) for analytical work and as the familiar "Bp-δ" and "Bu-δ" diagrams for design purposes. As "trial & error" design methods performed by hand in all engineering disciplines gradually transcended to numerical manipulation by the modern digital computer, the necessity for the adaption of the Series results to a format suitable for use in computer-aided design methods became obvious. This was accomplished through multiple regression analysis of the original open-water test data of the 120 propeller models in the Series and presented in the form of polynomial expressions for "K_T" and "K_Q" [Refs. 1,2].

The adaptation of the Wageningen B-Screw Series polynomials to various types of propeller selection problems formulated

for computer solution has been implemented recently by two authors. Triantafyllou [Ref. 3] and, of late, Markussen [Ref. 4] presented different propeller selection problems and proposed different schemes for computer-aided "optimized" solutions. In short, specific expressions for the constraints imposed and the objective (optimality condition) to be maximized, expressed in terms of a number of design variables and parameters, were developed. Then, each system of equations was solved by a Newton-Raphson method to give a solution set of the design variables which maximized the objective and met all constraints.

Rather than formulating and coding a different optimization scheme each time a propeller selection problem presents a different combination and number of design parameters, variables and constraints, a better approach would involve formulating the problem (constraints and objective function) once in terms of all design parameters and variables and utilizing a general purpose optimization scheme which can handle any combination and number of constraints and design variables. This alternative certainly allows the designer more flexibility in solving his problem. Moreover, it eliminates repetitive coding and debugging associated with the implementation of a computer-sided solution for each particular design problem.

B. PROBLEM STATEMENT

The problem, then, is that the previously cited computer-aided "optimized" solutions to the propeller selection problem are not broad enough in capability to handle variations in the problem formulation. The objective of this thesis is to apply an available general purpose optimization computer code to the solution of various propeller selection problems encountered in Preliminary Ship Design in order to enhance the flexibility of the selection procedure.

C. SCOPE

To achieve the stated objective, the general purpose non-linear optimization code CONMIN [Refs. 5,6] together with the engineering synthesis code COPES [Ref. 7] (hereafter referred to collectively as COPES/CONMIN) is utilized in the solution of the three previously cited preliminary design propeller selection problems. Using the Wageningen B-Screw Series propeller characteristics expressed in polynomial expressions of various design variables, three "analysis" codes, required by COPES/CONMIN, are developed in such a way that various combinations of design variables and constraints are used, thereby demonstrating the applicability of the COPES/CONMIN optimization program in the solution of propeller selection problems.

D. THESIS ORGANIZATION

The remainder of the thesis is organized in the following manner.

Chapter II presents a short description of the optimization problem in general terms and a follow-on discussion of the COPES/CONMIN optimization program and the mathematical techniques employed therein.

Chapter III introduces definitions and concepts applicable to the propeller selection problem. A subsequent discussion on the Wageningen B-Screw Series is followed by final comments on constraints imposed on the propeller selection problem.

Chapter IV presents the formulation of the propeller selection problem as a design optimization problem which can be solved using COPES/CONMIN.

Chapter V discusses the background, formulation and programming utilized in estimating a propeller blade's weight for subsequent consideration as an objective function.

Chapter VI reviews the author's modifications to the propeller strength analysis developed by Schoenherr [Ref. 8] in the early 1960's for the American Bureau of Shipping. A subsequent discussion on the programming details of FORTRAN codes, which are utilized for the determination of adequate propeller blade strength, completes the chapter.

Chapter VII reviews the formulation and programming for the analysis code which is used in solving propeller selection problems represented by Design Case No. 1. Sample solutions are presented and compared to those presented previously by other authors.

Chapters VIII and IX consider Design Case No. 2 and Design Case No. 3 selection problems, respectively, in a similar fashion to Chapter VII.

Chapter X, the final chapter, presents the author's conclusions and recommendations.

As a final note, all computer coding presented in this thesis is done in FORTRAN IV, the language used by COPES/CONMIN. For the reader's convenience, Appendix A provides a cross-reference of the symbols presented throughout the thesis to appropriate FORTRAN variable names appearing in the author's codes.

II. OPTIMIZATION

A. INTRODUCTION

The purpose of this chapter is to introduce definitions and concepts used in the formulation and solution of the general optimization problem. Then, a short discussion on the theory and implementation details of COPES/CONMIN is presented.

For further study on the theory and methods of optimization, the reader is directed to the texts by Fox [Ref. 9], Fiacco and McCormick [Ref. 10], and Himmelblau [Ref. 11].

B. DEFINITIONS

Before discussing the techniques of optimization and their application to engineering problems, some preliminary definitions of basic terminology should be stated. Terms which have relevant significance are:

1) Parameters--The numerical quantities for which values are assigned to produce a design are called parameters. From this, it follows that a design may be specified by a vector D containing "p" components, each of which is associated with a parameter. That is:

$$\bar{D} = \begin{Bmatrix} D_1 \\ \cdot \\ \cdot \\ \cdot \\ D_p \end{Bmatrix} \qquad (2.1)$$

However, in a design process, the parameters are determined by some logical procedure through analysis of some kind. Some might take on fixed values to become "preassigned" parameters. Interrelationships among other parameters might exist so that only some of the parameters are changed when one design is compared to another. This consequence leads to the definition of "design variable".

2) Design Variables--The parameters for which values are chosen in some fashion to produce a design are called design variables. They represent an ordered collection of components which is a subset of the design vector $\bar{D}$. This subset is unique in that its components are "variable", i.e., they may take on different values in the design process. Having "preassigned" or fixed some of the design's parameters and only allowing the remaining "design variables" to change, leads to the conclusion that a design is now uniquely specified by a vector $\bar{X}$ containing "n" components ($n \leq p$), each of which is associated with a design variable. That is:

$$\bar{X} = \begin{Bmatrix} X_1 \\ \vdots \\ X_n \end{Bmatrix} \tag{2.2}$$

3) Objective Function--The computable function of all or some of the design's preassigned parameters and/or design variables, with respect to which the design is to be optimized, is called the objective function. Single valued in

quantitative terms, the objective function's minimum or maximum value represents the "best" obtainable or "optimized" design. It is expressed as $F(\bar{D})$ to show its dependence on the design's parameters. But, since a design can be uniquely defined by $\bar{X}$ alone, then clearly $F(\bar{X})$ suffices as an expression for the objective function.

4) Constraints--Restrictions on the design which must be satisfied in order to produce an acceptable design are called constraints. A constraint may be classified as a "side" or a "behavior" constraint. A side constraint restricts or bounds the range of the design for reasons other than direct consideration of performance. The side constraint on the "i"th design variable may be expressed as:

$$X_i^{lower} \leq X_i \leq X_i^{upper} \quad i = 1,\ldots,n \tag{2.3}$$

A constraint derived from those performance or behavior requirements that are explicitly considered is called a behavior constraint. Most often, it appears as a computable functional relation involving the design's parameters, both preassigned and variable alike. The relation may be an inequality so that the "j"th of "m" inequality constraints can be expressed as:

$$G_j(\bar{D}) \leq 0 \quad j = 1,\ldots,m \tag{2.4}$$

Alternatively, the relation may be an equality on the "k"th of "ℓ" equality constraints expressed as:

$$H_k(\bar{D}) = 0 \qquad k = 1,\ldots,\ell \tag{2.5}$$

Of noteworthy importance here is that, as before, if some of the design's parameters are preassigned, then the resulting design is that defined by $\bar{X}$ which contains only the parameters that can be varied in the design process, i.e., the design variables. Therefore, constraints imposed upon the design may be expressed under one equation as:

$$\begin{aligned} G_j(\bar{X}) &\leq 0 && j = 1,\ldots,m \\ H_k(\bar{X}) &= 0 && k = 1,\ldots,\ell \\ X_i^{lower} &\leq X_i \leq X_i^{upper} && i = 1,\ldots,n \end{aligned} \tag{2.6}$$

A final form for constraints is that of the discrete-valued design variable.

5) Feasible Design--A design in which specified constraints are satisfied is called a feasible or "acceptable" design.

6) Infeasible Design--A design in which constraints are violated is called an infeasible or "unacceptable" design.

C. PROBLEM STATEMENT

If one presupposes that a range of designs exists within a selected design concept, then it follows that different

methodologies also exist by which one may choose the parameters which describe the design. One such method is optimization where parameters are chosen in a way that the design will satisfy all of the limitations and restrictions imposed upon it and will be "best" in some sense. In view of the foregoing definitions, optimization is then a selection method applied to a design problem by which an objective function $F(\bar{D})$ is minimized to produce an acceptable design which satisfies a certain set of requirements called constraints.

Formulated mathematically, the general, non-linear, constrained optimization problem may be stated under one equation as:

$$\begin{aligned} &\text{Minimize:} && F(\bar{D}) = OBJ \\ &\text{Subject to:} && G_j(\bar{D}) \leq 0 && j = 1,\ldots,m \\ &&& H_k(\bar{D}) \leq 0 && k = 1,\ldots,\ell \\ &&& X_i^{lower} \leq X_i \leq X_i^{upper} && i = 1,\ldots,n \end{aligned} \tag{2.7}$$

Again, as pointed out in the previous section, the design may be uniquely defined by just its design variables as specified by $\bar{X}$ when some parameters are preassigned. Thus, the general, non-linear, constrained optimization problem can now be stated under one equation as:

$$
\begin{aligned}
&\text{Minimize:} && F(\bar{X}) = OBJ && \\
&\text{Subject to:} && G(\bar{X}) \leq 0 && j = 1,\ldots,m \\
& && H_k(\bar{X}) = 0 && k = 1,\ldots,\ell \\
& && X_i^{lower} \leq X_i \leq X_i^{upper} && i = 1,\ldots,n
\end{aligned} \tag{2.8}
$$

Solutions methods for this optimization problem are abundant. Those pertaining to the linear and quadratic optimization problems involving a few design variables are most often presented in graphical or analytic form, although numerical schemes are, by no means, a dormant form. Structural and thermal problem solutions are most prevalent. However, as the optimization problem becomes more complex in terms of non-linear relationships among an increasing number of design variables and of an increased number of design constraints, numerical or mathematical programming techniques dominate the solution methods.

To limit the scope of this discussion, only the numerical techniques relevant to COPES/CONMIN will be considered. For more background on optimization techniques and applications, the reader is directed to a recent paper by Vanderplaats [Ref. 12] which presents a concise, but thorough, qualitative review of optimization. Although this paper deals exclusively with the application of design optimization to structural problems, it also contains a very extensive and current list of references on general techniques and applications of optimization.

D. COPES/CONMIN

As previously stated in Chapter I, COPES/CONMIN is the collective acronym for the FORTRAN program utilizing the optimization code CONMIN and the synthesis code COPES. COPES stands for COntrol Program for Engineering Synthesis; CONMIN is an acronym for CONstrained function MINimization.

1. CONMIN

CONMIN is a FORTRAN program, in subroutine form, which solves the general non-linear constrained optimization problem as stated:

$$\begin{aligned} &\text{Minimize:} \quad F(\bar{X}) = OBJ \\ &\text{Subject to:} \quad G_j(\bar{X}) \leq 0 \qquad j = 1,\ldots,m \qquad (2.9) \\ &\qquad\qquad X_i^{lower} \leq X_i \leq X_i^{upper} \quad i = 1,\ldots,n \end{aligned}$$

Equation (2.9) applies to the entire statement. Observe that equation (2.9) differs from equation (2.8) in that the equality constraint set, given by $H_k(\bar{X}) = 0$, is not specified. This is because the version of COPES/CONMIN used in this study does not consider these types of constraints. However, this will not pose any difficulty in solving the propeller selection problems previously cited.

Again, $F(\bar{X})$ is the objective function (OBJ). The vector $\bar{X}$ contains the "n" design variables (NDV). $G_j(\bar{X})$ are the "m" inequality behavior constraints (NCON) imposed on the optimization problem; X_i^{lower} and X_i^{upper} are the

respective lower and upper side constraints which bound the "design space" over which $F(\bar{X})$ and $G_j(\bar{X})$ are defined. As functional relationships involving $\bar{X}$, $F(\bar{X})$ and $G_j(\bar{X})$ may be implicit or explicit, but, in any event, must be continuous and have finite numerical values.

When the inequality condition of equation (2.9) is not satisfied, i.e., $G_j(\bar{X}) > 0$ for any constraint, the constraint is said to be violated. If the equality condition is met, i.e., $G_j(\bar{X}) = 0$ for any constraint, the constraint is said to be active. And, finally, if the inequality condition is satisfied, i.e., $G_j(\bar{X}) < 0$, for any constraint, that constraint is termed inactive. Any design, defined by $\bar{X}$, which satisfies the inequalities of equation (2.9) is designated as a feasible design. Likewise, any one which violates these inequalities is termed an infeasible design. The feasible design with the minimum objective function value, often referred to as the "minimum feasible design", will, therefore, be the optimum design.

During the optimization process, CONMIN employs the Fletcher-Reeves algorithm [Ref. 13] for locally unconstrained problems, and Zoutendijk's method of deasible directions [Refs. 14,15] for locally constrained problems, in a numerical procedure which attempts to minimize the objective function, $F(\bar{X})$ = OBJ, until one or more of the constraints, $G_j(\bar{X})$, becomes active. The numerical search procedure begins with an initial $\bar{X}$ vector which may or may not specify a feasible

design. Modifications are included in CONMIN so that, if the initial design is infeasible, a feasible solution will be obtained with minimal increase in $F(\bar{X})$. By iteratively updating the design vector $\bar{X}$ by the following relation:

$$\bar{X}^{(q+1)} = \bar{X}^{(q)} + \alpha^* \bar{S}^{(q)} \qquad (2.10)$$

the optimization process continues by following the constraint boundaries in a direction of search $\bar{S}$ so that the value of $F(\bar{X})$ decreases with each iteration q. The scalar α^* defines the distance of travel in the direction of search $\bar{S}$. The process terminates when a vector $\bar{X}$ is found such that no further decrease in $F(\bar{X})$ can be made. The vector $\bar{X}$ is considered to be optimal and, at least, a local minimum.

CONMIN can be used alone as a subroutine in any FORTRAN program where numerical optimization is desired. However, in order to make the optimization process more "user-friendly", CONMIN has been coupled to COPES in order to simplify its application to various types of problems. Further information on CONMIN can be found in previously cited references [5] and [6].

2. COPES

COPES is a FORTRAN program that provides automated design and trade-off capability to the design engineer. It utilizes the optimizer CONMIN to provide the following six specific capabilities:

1) simple analysis

2) optimization

3) sensitivity analysis

4) two variable function space analysis

5) optimum sensitivity

6) optimization using approximation techniques

During the execution of COPES, say for optimization, three principal tasks are performed:

1) data management on the design variables and constraints through location assignments in a FORTRAN common block called GLOBCM.

2) decision process control on the attainment of an optimal design vector $\bar{X}$ through multiple calls to the optimizer until a minimum or maximum value of *OBJ is achieved and* all $G_j(\bar{X})$ are satisfied.

3) evaluation of OBJ and $G_j(\bar{X})$ at each $\bar{X}^q$ and $\bar{X}^{q+1}$ when ICALC = 2 through multiple calls to the user-provided analysis subprogram, SUBROUTINE ANALIZ.

For the application under consideration in this study, only the optimization capability will be used. Therefore, further elaboration on the other capabilities is not warranted.

Reference [7] is the user's manual for COPES/CONMIN. Details on the mechanics of user implementation are presented with subsequent illustration by example. The reader is, therefore, encouraged to familiarize himself with the reference. However, at this point, it is sufficient to be aware of the fact that a user of COPES/CONMIN is required to:

1) provide a FORTRAN subroutine called ANALIZ which performs the input of preassigned parameters, the evaluation of the objective function and constraints during the analysis phase of the optimization search and the output of the results.

2) provide an assembled deck of control cards required by COPES.

E. CONCLUDING NOTE

The field of optimization is both extensive and complex and, therefore, the foregoing presentation is, by no means, complete in every detail. However, it is felt that the preceding overview, in conjunction with the cited references, covers the necessary prerequisites that will enable the reader to follow the application of *COPES/CONMIN* to the various propeller selection problems in the chapters that follow.

III. POWERING, PERFORMANCE AND PROPELLERS

A. INTRODUCTION

The purpose of this chapter is to present an overview of the terminology and concepts that pertain to ship propulsion, propeller selection and the use of model propeller test data. Initially, fundamental definitions used in ship powering problems are presented. This is followed by a discussion of the "classic" types of propeller design/selection problems encountered by the naval architect and marine and naval engineers. Propeller model testing and propeller performance characteristics are reviewed next. The chapter is completed with a discussion of the Wageningen B-Screw Series.

The goal here is brevity. The reader is, therefore, encouraged to investigate the references cited for further details.

B. DEFINITIONS

Some fundamental terms associated with most propeller design/selection problems are:

1) Effective Horsepower (P_E)--power required to tow the "bare" hull (without propeller; rudder and appendage allowance assumed included) that generates a given resistance (R_T) at a given speed (V). It is determined by:

$$P_E = \frac{R_T V}{550} \qquad (3.1)$$

2) Thrust Horsepower (P_T)--power delivered to water by a propeller developing a thrust force (T) and moving at a speed of advance (V_A) without the influence of a hull form ahead of it. P_T is determined by:

$$P_T = \frac{T\ V_A}{550} \tag{3.2}$$

3) Delivered Horsepower (P_D)--power delivered by shaft to propeller, normally specified at the outboard side of the stern tube. Q_S is the torque delivered to the propeller; n_P is the revolution rate of the shaft and, consequently, the propeller. P_D is determined by:

$$P_D = \frac{2\pi\ Q_S\ n_P}{550} \tag{3.3}$$

4) Shaft Horsepower (P_S)--power delivered to the inboard side of the stern tube having a transmission efficiency of η_S. P_S is determined by

$$P_S = \frac{P_D}{\eta_S} \tag{3.4}$$

5) Brake Horsepower (P_B)--power delivered by the prime mover at connection flange to the power train. While P_B is normally associated with the prime mover's rated power at this connection (BHP), it can also be specified from the power train/propeller side as:

$$P_B = \frac{P_S}{\eta_B \eta_G} \qquad (3.5)$$

where η_B and η_G are, respectively, the bearing system and reduction gear transmission efficiencies.

6) Thrust deduction factor (1-td)--ratio of the tow resistance (R_T) to the thrust (T) provided by the propeller. It is determined by

$$(1\text{-td}) = \frac{R_T}{T} \qquad (3.6)$$

7) Wake Factor (Taylor's) (1-wt)--ratio of the speed of advance (V_A) to the ship's speed (V). It is given by:

$$(1\text{-wt}) = \frac{V_A}{V} \qquad (3.7)$$

8) Advance Ratio (J)--a non-dimensional value, associated with propeller test data presentation (see figure (3.1), given by the following relation:

$$J = \frac{V(1\text{-wt})}{n_P D} = \frac{V_A}{n_P D} \qquad (3.8)$$

9) Thrust Coefficient (K_T)--a non-dimensional value associated with the thrust force (T) developed by a propeller of diameter D which is turning at a rate n_P and operating in a fluid of density ρ. It is defined by the following expression:

$$K_T = \frac{T}{\rho\, n_P^2\, D^4} \tag{3.9}$$

10) Torque Coefficient (K_Q)--a non-dimensional value associated with the torque (Q_P) absorbed by a propeller of diameter D which is turning at a rate n_P and operating in a fluid of density ρ. It is defined by the following expression:

$$K_Q = \frac{Q_P}{\rho\, n_P^2\, D^5} \tag{3.10}$$

11) Open Water Efficiency (η_o)--the ratio of P_T to P_D for a propeller in open water conditions, with a uniform inflow velocity field at a speed of advance V_A. It is expressed as:

$$\eta_o = \frac{P_T}{P_D} = \frac{T\, V_A}{2\pi\, n_P\, Q_S} = \frac{J\, K_T}{2\pi\, K_Q} \tag{3.11}$$

12) Hull Efficiency (η_H)--a ratio of work done on the ship to that done by the propeller expressed as:

$$\eta_H = \frac{P_E}{P_T} = \frac{R_T\, V}{T\, V_A} = \frac{(1-td)}{(1-wt)} \tag{3.12}$$

13) Relative Rotative Efficiency (η_R)--the ratio of the actual, behind-hull efficiency to the open water efficiency. The value of η_R does not, in general, depart from the value

of 1.0. Most often, η_R varies between 0.95 and 1.0 for twin-screw ships and between 1.0 and 1.1 for single screw ships.

Applicable units for the terms in the expressions above are:

1) horsepower (hp)--P_E, P_T, P_S, P_D and P_B
2) pounds (lbf)--R_T, T
3) feet/second (ft/sec)--V, V_A
4) foot-pounds (ft-lbf)--Q_S, Q_P
5) feet (ft)--D
6) revolutions/second (rps)--n_P
7) revolutions/minute (rpm)--$N_P = n_P/60.0$

The quantities T, V_A, D, Q_P and n_P are obtained from the propeller test data results. The quantities R_T and V are specified from the design point on the *R-V* curve for the hull under study. The quantity ρ is a property of the fluid in which the hull and propeller operate. And, finally, η_B, η_G and η_S are characteristics of the bearing, gear and stern tube systems. In preliminary design studies, nominal values, based on previous designs, are usually assumed unless, of course, these systems have been selected and actual values can be specified.

C. POWERING CONCEPTS

1. Basic Relations

Simply stated, the fundamental powering relationship to be solved in ship propulsion and powering problems is:

$$P_E = \frac{(1-td)}{(1-wt)} \cdot \eta_R \eta_o P_D \qquad (3.13)$$

Utilizing the definitions just presented, equation (3.13) can be rewritten as:

$$\frac{R_T V}{550} = \frac{(1-td)}{(1-wt)} \cdot \eta_R \eta_o \cdot \frac{2\pi Q_S n_P}{550} \qquad (3.14)$$

Rearranging terms of equation (3.14) gives:

$$\frac{R_T}{(1-td)} \cdot \frac{(1-wt)V}{550} = \eta_R \eta_o \cdot \frac{2\pi Q_S n_P}{550} \qquad (3.15)$$

And, finally, when substitutions are made, equation (3.15) becomes:

$$\frac{T V_A}{550} = \frac{T(1-wt)V}{550} = \eta_R \eta_o \cdot \frac{2\pi Q_S n_P}{550} \qquad (3.16)$$

Equations (3.14), (3.15), and (3.16) provide the basis for different approaches to the solution of a typical powering problem. More background and information on the definitions and equations presented above may be found in Chapter VI, Sections 10-16 in the text by Comstock [Ref. 16] and O'Brien's book [Ref. 17].

2. Approaches to the Powering Problem

From equation (3.16), three types of propeller selection problems are discernible. In the first instance, the propeller thrust T and the propeller's speed of advance V_A

are taken as known quantities. The fact that T is known substantiates the "Thrust Approach" nomenclature given to this type of selection problem. In the preliminary (or, in some circles, conceptual) ship design phase, the specification of T is based upon the requirement imposed by the resistance of the ship (R_T) at its design speed (V) (or, the effective horsepower (P_E) at V) and estimates of wt and td in the absence of wake surveys and self-propulsion data from model tests. Essentially, the thrust delivered by a selected propeller must provide, at least, the thrust required for the ship hull under study. The objective in the "Thrust Approach" selection problem is to determine, by logical means, the appropriate values of Q_S and n_p when the open water efficiency (η_o) is set by the selected propeller and its performance characteristics.

In the second instance, the delivered torque (Q_S) and the propeller shaft speed (n_p) are taken to be known. The "Power Approach" nomenclature is given to propeller selection problems of this type because P_D is known. Here, with the shaft and propeller speeds being equal, the torque absorbed by the propeller (Q_p) must be, at least, equivalent to the delivered torque (Q_S). The corresponding objective in the "Power Approach" selection problem is to determine, by logical means, the expected ship speed (V) (or, the speed of advance (V_A)) and the associated thrust (T) that can be developed when the open water efficiency (η_o) is, again, set by the selected propeller and its performance characteristics.

The final, and most familiar, types of propeller selection problem occurs when T, V_A or V, Q_S and n_p are all known. From equation (3.16), the open water efficiency (η_o) is now established as a requirement to be met. The objective is, simply, to select a propeller whose open water efficiency (η_o), developed thrust and absorbed torque are equivalent to or "match" the requirements imposed. Obviously, this approach on the selection problem has been designated as a "matching problem".

The reader is directed to the paper by Vassilopoulos [Ref. 18] for further information.

D. PROPELLER PERFORMANCE CHARACTERISTICS

Up until the late 1950's, much of the knowledge about the performance of propellers has been gained from experience with models. To study the relationships governing their behavior, a model propeller is built and run in a towing tank without any hull ahead of it. This is done by running the propeller on a long shaft projecting well ahead of a narrow, hydrodynamically shaped pod or "propeller boat" which contains the driving mechanism and recording apparatus and is attached to the towing carriage. The propeller advances into undisturbed fluid (usually water of density ρ and kinematic viscosity ν) so that the speed of advance (V_A) is known and the flow into the "disc" swept by the turning blades is uniform. For the model propeller of diameter (D) under test, readings of thrust (T), torque (Q_S) and shaft revolutions (n_p)

are recorded over a range of values for speed of advance (V_A) in this "open water" condition.

Using the laws of similitude, the collected data is reduced and scaled appropriately into the familiar functional relationships between the advance ratio (J) and the non-dimensional coefficients of propeller performance. These coefficients or performance characteristics, defined previously, are:

1) Thrust Coefficient (K_T)
2) Torque Coefficient (K_Q)
3) Open Water Efficiency (η_o)

Figure (3.1) graphically depicts the relationship between J and K_T and K_Q derived from test data for a propeller defined by a specific expanded area ratio (A_E/A_O), pitch-diameter ratio (P/D), number of blades (Z) and thickness-to-chord ratio (t/c).

Definitions of these terms with graphical illustrations pertaining to various aspects of propeller geometry can be found in Section 15 of references [16], [17] and in van Manen's publication [Ref. 19].

More recently, highly analytical theories (lifting line, modified lifting line, lifting surface, etc.) for use with high-speed digital computers have been formulated and subsequently used in "modeling", in a mathematical sense, the propeller and its behavior in the "wake adapted" (or, behind hull) condition as well as the "open water" condition.

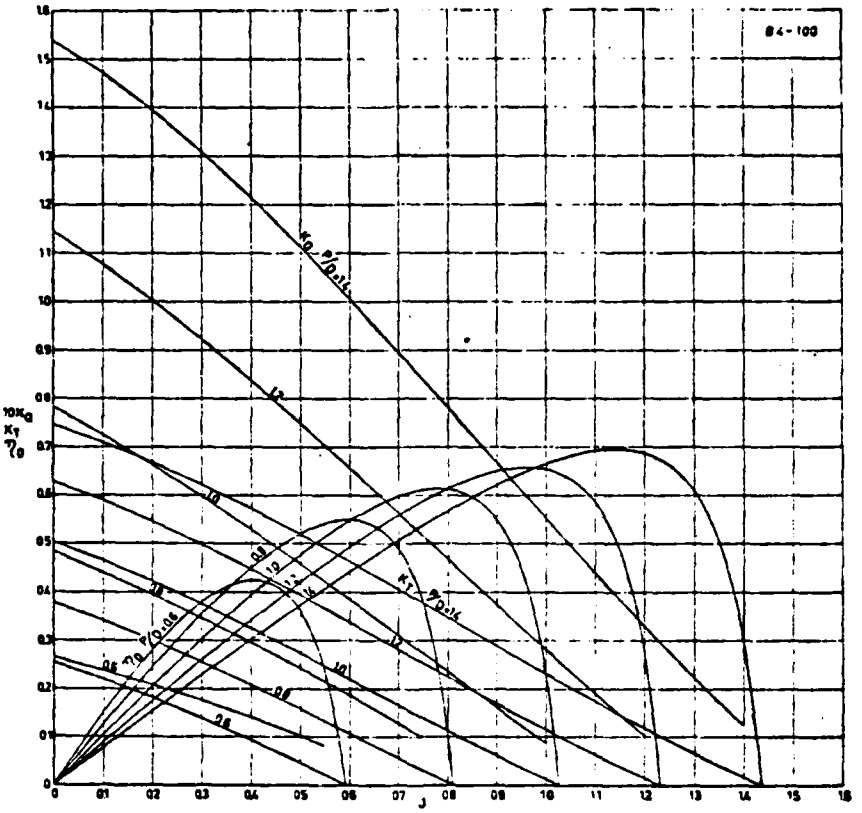


Figure 3.1 Open Water Test Results--B 4-100 Series Propeller

Additional benefits derived from this approach to propeller performance analysis include:

1) determination of blade section profiles along the propeller's blade radius (R) to achieve uniform lift and internal stress distributions;

2) computation of "off-design" performance characteristics in all quadrants;

3) subsequent determination of hull surface forces, bearing loads and spindle torques induced by the propeller;

4) prediction of steady and unsteady stress distributions in the propeller blade using the finite element method on the blade of the propeller under study.

Obviously, this approach to propeller performance analysis serves to:

1) eliminate the time-consuming and expensive model construction and testing of propellers in tow tanks and cavitation tunnels;

2) eliminate the "scaling" discrepancies which inhibit the reliability of design charts and model propeller data;

3) eliminate those design charts altogether.

As in the case with model experiments, however, the ultimate objective remains the same, i.e., establishing the performance characteristics of the propeller in terms of K_T, K_Q and as functions of J. Having these relationships enables the ship designer to proceed in solving the power equation (equation (3.13)) through any of the approaches previously discussed.

E. THE WAGENINGEN B-SCREW SERIES

1. Background

The model test data of the Wageningen B-Screw Series have been selected for use in the powering problems to be solved utilizing COPES/CONMIN. The choice was driven by the following considerations:

1) the Series is widely known and, despite its growing obsolescence, is still used in preliminary ship design studies.

2) the availability of previous investigations [Refs. 3,4] which utilized the series, for comparative analysis of optimization results.

3) the applicability of the polynomial expressions for K_T and K_Q to computer-aided analysis.

The Series tests were conducted from 1940 through 1960 and, therefore, represent propeller designs (principally naval and merchant applications) and design philosophy of that era.

Specifically, the Series consists of 120 model propellers. As is customary in methodical or systematic model propeller series testing, the number of blades (Z), expanded area ratio (A_E/A_O) and pitch-diameter ratio (P/D) are varied systematically, while the blade outline, the profile of the blade's cross section along the blade radius, blade cross section maximum thickness (t), blade section chord length (c), diameter (D) and propeller hub-to-diameter ratio (d/D) were kept constant for given values of A_E/A_O and Z.

Table (I) summarizes the variations in Z and A_E/A_O for each set of model propellers having pitch-diameter ratios (P/D) of 0.4, 0.6, 0.8, 1.0, 1.2 and 1.4.

TABLE I

Summary of the Wageningen B-Screw Series

Blade number Z \ Blade area ratio A_E/A_o															
2	0.30														
3		0.35			0.50			0.65			0.80				
4			0.40			0.55			0.70			0.85		1.00	
5				0.45			0.60			0.75					1.05
6					0.50			0.65			0.80				
7						0.55			0.70			0.85			

2. Series Results

The test results of the Wageningen B-Screw Series were originally presented in the form of Bp-δ, Bu-δ and K_T, K_Q, and -J diagrams. As stated in Chapter I, multiple regression analysis was performaed (again, [Refs. 1,2]) on the results to produce the polynomial expressions for K_T and K_Q. The open water efficiency (η_o), as a function of J, follows from equation (3.11). The correction for "scale effects" was achieved by using Lerb's method of equivalent profiles [Ref. 20]. Although Triantafyllou's thesis [Ref. 21] suggests an improved method for scale correction, the results of Reference [2] will be used in this study.

In propeller selection problems which use this Series, values for K_T and K_Q are defined as:

$$K_T = f_1(J, P/D, A_E/A_O, Z, t^*/c_{.75R})$$
$$K_Q = f_2(J, P/D, A_E/A_O, Z, t^*/c_{.75R}) \tag{3.17}$$

To compute K_T and K_Q, the following equations are used:

$$K_T = K_T' + \Delta K_T$$
$$K_Q = K_Q' + \Delta K_Q \tag{3.18}$$

The polynomial expressions found in Tables (5) and (6) of Reference [2] are then used to evaluate to components K_T', K_Q', ΔK_T and ΔK_Q.

Table (5) in Reference [2] lists the coefficients used in the polynomial expressions for K_T' and K_Q' at an equivalent Reynolds number ($Rn_{.75R}$) of 2×10^6. It is defined as:

$$Rn_{.75R} = \frac{c_{.75R} \sqrt{(V_A)^2 + (0.75\pi n_p D^2)}}{\nu} \tag{3.19}$$

where:

ν = kinematic viscosity of the fluid (ft^2/sec);

$c_{.75R}$ = blade section chord length at 3/4 propeller radius (.75R) in feet (ft).

To account for "other effects", coefficients ΔK_T and ΔK_Q are introduced. Table (6) in Reference [2] lists the coefficients used in the polynomial expressions for these coefficients. "Other effects" include the operation of the propeller at an equivalent Reynolds Number different from 2×10^6. Also, variations in other parameters which define the propeller's geometry, specifically t/c values different from the ones fixed by the Wageningen propellers, are taken into account by corrections to the equivalent Reynolds number. By keeping the blade section's chord length (c) at the value of the Wageningen propeller, a change in a blade section's maximum thickness from the standard one defined by the Series (t) to one preferred in the selection (t*) produces a new equivalent Reynolds number ($Rn^*_{.75R}$) given by:

$$Rn^*_{.75R} = \exp\left[4.6052 + \left\{\sqrt{\frac{1+2(t/c_{.75R})}{1+2(t^*/c_{.75R})}}\ (\ell n\ Rn_{.75R} - 4.6052)\right\}\right] \tag{3.20}$$

where:

$Rn^*_{.75R}$ = the new equivalent Reynolds number;

$(t^*/c)_{.75R}$ = new equivalent t/c at 3/4 propeller radius;

$Rn_{.75R}$ = the Reynolds number computed by equation (3.19);

$(t/c)_{.75R}$ = standard equivalent t/c at 3/4 propeller radius for Wageningen propellers.

For the Wageningen B-Screw Series, the standard equivalent t/c is given by:

$$t/c_{.75R} = \frac{(0.0185 - 0.00125Z)Z}{2.073\ A_E/A_O} \qquad (3.21)$$

Further details on blade section geometry will be addressed in Chapter V. Reference [2] contains background and other information on the equations above.

3. Limitations on Series Data

In utilizing the Wageningen B-Screw Series in any propeller selection problem, the following restrictions apply to the Series data:

1) Number of Propeller Blades (Z)--The Series considers only propellers with numbers of blades as shown in Table (I). Therefore,

$$Z = 2, 3, 4, 5, 6 \text{ or } 7 \qquad (3.22)$$

However, the two bladed propeller, i.e., Z = 2, is not very common in conventional merchant and naval ship designs and, therefore, is not included in this study.

2) Equivalent Reynolds Number--The Series data, as published, is valid only in the range of equivalent Reynolds numbers given by:

$$2 \times 10^6 \leq Rn_{.75R} \leq 2 \times 10^9 \qquad (3.23)$$

If the equivalent t/c is varied from the standard equivalent value $(t/c)_{.75R}$, then the new equivalent Reynolds number $(Rn^*_{.75R})$, which results from this variation, must lie within the same limits. That is,

$$2 \times 10^6 \leq Rn^*_{.75R} \leq 2 \times 10^9 \qquad (3.24)$$

These limits are appropriate for full-size propellers. For example, given the following:

a) wt = .22

b) V = 20 (knots)

c) N_p = 104 (rpms)

d) D = 25 (ft)

e) $c_{.75R}$ = 4.0 (ft)

f) $\nu = 1.2285 \times 10$ (ft^2/sec)

the value for $Rn_{.75R}$ is equal to 3.619×10^7.

3) Pitch-diameter Ratio (P/D)--The series data considers only pitch diameter ratios in the range given by:

$$0.4 \leq P/D \leq 1.4 \qquad (3.25)$$

4) Advance Ratio (J)--An inspection of the Series results in graphical format shows that J varies over a range given by:

$$0 < J \leq 1.6 \qquad (3.26)$$

5) Expanded Area Ratio (A_E/A_O)--Using Table (I), A_E/A_O varies over certain ranges depending on Z. This is stated as:

$$0.35 \leq A_E/A_O \leq 0.8 \qquad Z = 3 \tag{3.27}$$

$$0.40 \leq A_E/A_O \leq 1.0 \qquad Z = 4 \tag{3.28}$$

$$0.45 \leq A_E/A_O \leq 1.05 \qquad Z = 5 \tag{3.29}$$

$$0.50 \leq A_E/A_O \leq 0.8 \qquad Z = 6 \tag{3.30}$$

$$0.55 \leq A_E/A_O \leq 0.85 \qquad Z = 7 \tag{3.31}$$

6) Hub diameter-to-Propeller Diameter Ratio (d/D)--From Table 37, Section 17 of Reference [16], the Series data requires that:

$$d/D = 0.18 \qquad Z = 3,7 \tag{3.32}$$

$$d/D = 0.167 \qquad Z = 4,5,6 \tag{3.33}$$

F. SUMMARY

From the preceding discussions, the following observations can be made:

1) the "Design Cases", defined in Chapter I, are examples of the powering equation solution approaches. That is, Design

Case No. 1 constitutes a "Thrust Approach" problem; Design Case No. 2, a "Power Approach" one; Design Case No. 3, a "Matching" problem.

2) equations (3.17) and (3.8) imply that an optimization solution to the "Design Cases" will involve P_E, V, wt, D, P/D, A_E/A_O, $(t^*/c)_{.75R}$, Q_S and n_P as possible design variables.

3) when viewed from the concepts on optimization presented in Chapter II, equations (3.25) through (3.31) constitute side constraints to an optimized solution of a propeller selection problem which uses the Wageningen B-Screw Series. Having noted these points, the propeller selection problem can now be formulated as a general, non-linear, constrained optimization problem.

IV. PROPELLER SELECTION--AN OPTIMIZATION PROBLEM

A. INTRODUCTION

The purpose of this chapter is to present the formulation of the propeller selection problem as an optimization problem that can be solved using COPES/CONMIN. Three usual restrictions considered by the designer in any propeller selection analysis are stated as constraints. Then, the components of $\overline{D}$ and $\overline{X}$ are assembled based on requirements from previously cited relationships. The restrictions considered by the designer and the limitations imposed by the use of the Wageningen B-Screw Series are presented in inequality constraint format. A formal statement of the propeller selection problem as an optimization problem is followed by a review of the GLOBCM common block format and the basic subprograms used in all three versions of SUBROUTINE ANALIZ that pertain to each Design Case.

The FORTRAN subprogram listings are found in Appendix B. Comment cards have been used extensively in the coding development to assist the reader.

B. DESIGNER'S CONSIDERATIONS

1. Propeller Size

The first restriction on the selection of any propeller is size. That is, the propeller race in the stern of the hull under consideration will only accommodate a

propeller of some given maximum diameter (D_{lim}). As a constraint on a selected propeller of diameter D, this may be written as:

$$D \leq D_{lim} \tag{4.1}$$

or, alternatively, as:

$$G_9(\bar{X}) = \frac{D}{D_{lim}} - 1 \leq 0 \tag{4.2}$$

2. Cavitation

Another item of importance in propeller selection is the cavitation phenomenon. When a propeller of given diameter D and expanded area ratio A_E/A_O is operating to produce a thrust T, the formation and subsequent collapse of water vapor bubbles on the blade surface, i.e., cavitation, is likely to occur if the localized surface pressures, usually on the "back" side of the blade, drop below the pressure at which the fluid would boil (p_{watvap}) in the surrounding environment. Avoidance of cavitation can be reasonably assured by selecting a propeller having certain geometric characteristics. A good empirical relationship that establishes these characteristics for propellers typified by the Wageningen B-Screw Series is the Keller Cavitation criterion [Ref. 2: p. 259]. It specifies the minimum required expanded area ratio ($A_E/A_{O\ min}$) to avoid cavitation and is given by:

$$(A_E/A_O)_{min} = \frac{(1.3 + 0.3Z)}{(p_{atm} + \rho \cdot acg\, h_{c\ell} - \rho_{watvap})} \cdot \frac{T}{D^2} + b \qquad (4.3)$$

where:

Z = number of blades;

T = developed thrust (lbf);

D = propeller diameter (ft);

p_{atm} = atmospheric pressure (psia);

p_{watvap} = fluid vaporization pressure (psia)

ρ = fluid density (lbf sec^2/ft^4)

acg = 32.174 (ft/sec^2)

$h_{c\ell}$ = depth to shaft centerline (ft)

b = constant: 0.1 for Z = 2, 0.2 for Z = 1.

As a constraint on the propeller selection, this requirement is writen as:

$$(A_E/A_O)_{min} \leq A_E/A_O \qquad (4.4)$$

or

$$G_{10}(\bar{X}) = \frac{(A_E/A_0)_{min}}{A_E/A_O} - 1 \leq 0 \qquad (4.5)$$

3. Strength

The final designer's consideration (for this study), included in the selection of a propeller, is that of strength.

Given the propeller's material (promat), selected from Table (II), and the loadings (T and Q_S) imposed, it is important to ensure that the blade's cross sections have proper dimensions (in an ideal sense, maximum blade section thickness (t*) and chord length (c)) to ensure adequate strength. Since the use of the B-Screw Series requires that the chord length (c) vary as a prescribed function of D, Z and A_E/A_O, as given in Table 1 of Reference [2], the adequacy for strength can be determined by an appropriately selected value for blade section maximum thickness-to-chord ratio (t*/c) alone. So, if t^*_{min} is the established minimum blade section maximum thickness, then the strength requirement follows from the constraint given by:

$$t^*_{min}/c = (t^*/c)_{min} \leq t^*/c \qquad (4.6)$$

The fact that blade section maximum thickness for the B-Screw Series varies linearly with the propeller radius (R) allows the strength constraint (equation (4.6)) to be evaluated at one section along the radius. This point is chosen to be at the 3/4 radius (.75R). Therefore, equation (4.6) becomes:

$$(t^*/c)_{.75R\ min} \leq (t^*/c)_{.75R} \qquad (4.7)$$

or

$$G_{11}(\bar{X}) = \frac{(t^*/c)_{.75R\ min}}{(t^*/c)_{.75}} - 1 \leq 0 \qquad (4.8)$$

Reference [2] suggests the following empirical relation for the minimum required equivalent blade section maximum thickness-to-chord ratio $(t^*/c)_{.75R\ min}$):

$$(t^*/c)_{.75R\ min} = \frac{Z\left\{0.0028+0.21\sqrt[3]{\frac{(2375-1125P/D)P_D}{4.123N_pD^3(S_c+\frac{D^2N_P^2}{12.788})}}\right\}}{2.073\ A_E/A_O} \tag{4.9}$$

where:

D = propeller diameter (ft);

P_D = delivered power (hp);

N_P = propeller revolution rate (rpm);

S_c = propeller material allowable stress (psi);

P/D = pitch-diameter ratio.

However, in Chapter VI of this thesis, an algorithm which employs the Schoenherr formulation [Ref. 8] with some modifications, is presented as an alternative to equation (4.9).

C. THE DESIGN VECTOR

In view of the preceding presentations on optimization and powering, the design vector $\bar{D}$ can be assembled for the general propeller selection problem utilizing the B-Screw Series. This vector is composed of preassigned parameters relating to environmental conditions, hull characteristics

and the propeller which are required for various equations and the design variables.

1. Parameters

a. Environmental

These parameters pertain primarily to the fluid conditions in which the propeller operates and to the atmosphere. Required for various calculations, they are:

1) fluid temperature (°F)--Temp
2) fluid density (lbf sec^2/ft^4)--ρ
3) fluid viscosity (ft^2/sec)--ν
4) fluid vaporization pressure (psia)--p_{watvap}
5) atmospheric pressure (psia)--p_{atm}

b. Hull Characteristics

These parameters pertain to certain details prescribed for the hull under study in the powering analysis. They are:

1) wake fraction--wt
2) thrust deduction--td
3) relative rotative efficiency --η_R
4) number of propellers--noscrw
5) shaft centerline depth (ft)--$h_{c\ell}$
6) propeller diameter limit (ft)--D_{lim}

c. Propeller

These parameters are specified in view of their discrete-valued nature. They are:

1) number of blades--Z
2) material--promat

Table (II) lists materials and properties considered in this study. These values are taken from Table (35), Section 15 of Reference [16].

TABLE II

Material Identifier Reference

promat	Material	Allowable Stress--Sc (psi)	Density--wd (lbf/in^3)
1	Cast Iron	3600--3950	.260
2	Cast Steel	5915--6265	.289
3	Type 2 Bronze	7200-7585	.305
4	Type 4 Ni-Al Bronze	8910--9430	.278
5	Stainless Steel	5400--5500	.283

2. Design Variables

In view of equations (3.13) through (3.17), the design variables common to all selection approaches are:

1) P_E
2) V
3) D
4) P/D
5) A_E/A_O
6) $(t^*/c)_{.75R}$
7) N_p
8) Q_S

The vectors $\overline{D}$ and $\overline{X}$ are shown schematically in figure (4.1).

$$\bar{X} = \begin{Bmatrix} P_E \\ V \\ D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \\ N_P \\ Q_S \end{Bmatrix} \qquad \bar{D} = \begin{Bmatrix} \text{Temp} \\ \rho \\ \nu \\ p_{watvap} \\ p_{atm} \\ wt \\ td \\ \eta_R \\ noscrw \\ h_{c\ell} \\ D_{lim} \\ Z \\ promat \\ P_E \\ V \\ D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \\ N_P \\ Q_S \end{Bmatrix}$$

Figure 4.1 Design Vectors $\bar{D}$ and $\bar{X}$

D. CONSTRAINTS

Besides the constraints imposed by equations (4.2), (4.5) and (4.8), equations (3.25) through (3.31) are rearranged to the format of constraints in equation (2.9). They are listed as follows:

1) Equivalent Reynolds Number--Equation (3.25) becomes:

$$1 \leq \frac{Rn^* .75R}{2 \times 10^6} \leq 1000 \tag{4.10}$$

Two constraints are derived:

$$G_3(\bar{X}) = 1 - \frac{Rn^* .75R}{2 \times 10^6} \leq 0 \tag{4.11}$$

$$G_4(\bar{X}) = \frac{Rn^* .75R}{2 \times 10^6} - 1000 \leq 0 \tag{4.12}$$

2) Expanded Area Ratio--Equations (3.27) through (3.31) become:

$$(A_E/A_O)_{lower}(Z) \leq A_E/A_O \leq (A_E/A_O)_{upper}(Z) \tag{4.13}$$

Two constraints are derived:

$$G_5(\bar{X}) = (A_E/A_O)_{lower}(Z) - A_E/A_O \leq 0 \tag{4.14}$$

$$G_6(\bar{X}) = A_E/A_O - (A_E/A_O)_{upper}(Z) \leq 0 \tag{4.15}$$

3) Advance Ratio--Equation (3.22) becomes:

$$0 \leq \frac{J}{1.6} \leq 1 \qquad (4.16)$$

Two constraints are derived:

$$G_1(\bar{X}) = \frac{-J}{1.6} \leq 0 \qquad (4.17)$$

$$G_2(\bar{X}) = \frac{J}{1.6} - 1 \leq 0 \qquad (4.18)$$

4) Equivalent Blade Section Maximum Thickness-to-Chord Ratio--Using equation (3.19), boundaries on the range of $(t^*/c)_{.75R}$ are defined by:

$$\frac{1}{2}(t/c)_{.75R} \leq (t^*/c)_{.75R} \leq 4(t/c)_{.75R} \qquad (4.19)$$

Two constraints are derived:

$$G_7(\bar{X}) = \frac{1}{2}(t/c)_{.75R} - (t^*/c)_{.75R} \leq 0 \qquad (4.20)$$

$$G_8(\bar{X}) = (t^*/c)_{.75R} - 4(t/c)_{.75R} \leq 0 \qquad (4.21)$$

E. OBJECTIVE FUNCTIONS

Upon consideration of equation (3.13), Design Case No. 1 and Design Case No. 2 require that the open water efficiency (η_o), given by equation (3.11), be maximized. In terminology related to optimization, this is stated as:

$$OBJ_{1,2} = -\eta_o \tag{4.22}$$

Design Case No. 3, the "matching" problem, requires that the blade weight (bldwt) be minimized. This is stated as:

$$OBJ_3 = \text{bldwt} \tag{4.23}$$

F. PROPELLER SELECTION OPTIMIZATION PROBLEM STATEMENT

As a general, non-linear constrained optimization problem to be solved by COPES/CONMIN, the propeller selection problem for all Design Cases may be stated as one equation given by:

$$\text{Minimize:} \quad F(\bar{X}) = OBJ_{1,2} \text{ or } OBJ_3 \tag{4.24}$$

$$\text{Subject to:} \quad G_j(\bar{X}) \leq 0 \qquad j = 1,\ldots,12$$

$$X_i^{lower} \leq X_i \leq X_i^{upper} \qquad i = 1,\ldots,8$$

The constraint $G_{12}(\bar{X})$ and the values for X_i^{lower} and X_i^{upper} will be specified according to each Design Case.

G. CODING FUNDAMENTALS

1. GLOBCM Common Block

The GLOBCM common block, required by COPES/CONMIN, is now assembled. Table (III) specifies the assignment locations for the FORTRAN variables which define objective functions, design variables and constraints.

2. SUBROUTINE ANALIZ

While each Design Case uses a different approach, all analyses are very similar. Therefore, each SUBROUTINE

TABLE III

Global Common (GLOBCM) Catalog

Global Location	FORTRAN Name	DEFINITION
1	ETAO	η_o
2	WEIGHT	bldwt
3	AEDVAO	A_E/A_O
4	DIA	D
5	N	$N_P = 60 \cdot n_P$
6	PE	P_E
7	PDIVD	P/D
8	QS	Q_S
9	TC75R	$(t^*/c)_{.75R}$
10	V	V (ft/sec)
11	RJCHL	$G_1(\bar{X})$--eqn (4.17)
12	RJCNU	$G_2(\bar{X})$--eqn (4.18)
13	R75RCL	$G_3(\bar{X})$--eqn (4.11)
14	R75RCU	$G_4(\bar{X})$--eqn (4.12)
15	AEAOCL	$G_5(\bar{X})$--eqn (4.14)
16	AEAOCU	$G_6(\bar{X})$--eqn (4.15)
17	TC75CL	$G_7(\bar{X})$--eqn (4.20)
18	TC75CU	$G_8(\bar{X})$--eqn (4.21)
19	POWBAL	$G_{12}(\bar{X})$--eqn (7.10) or (8.11) or (9.4)
20	DIACNU	$G_9(\bar{X})$--eqn (4.2) or (9.6)
21	AEAOCV	$G_{10}(\bar{X})$--eqn (4.5)
22	TCSTRS	$G_{11}(\bar{X})$--eqn (4.8)
23	RJ	J

ANALIZ shares a common structure and other common subroutines which perform calculations required in all cases. Appendices C, F and I contain, respectively, the source listings of SUBROUTINE ANALIZ for Design Case No. 1, Design Case No. 2 and Design Case No. 3.

a. Structure

The structure common to all cases follows accordingly:

1) all initialization of environmental, hull and propeller parameters is accomplished in the input section (ICALC = 1).

2) evaluation of K_T and K_Q, all constraints and appropriate objective functions ($-\eta_o$ or bldwt) are accomplished in the execution section (ICALC = 2).

3) output of results for each optimization problem is accomplished in the output section (ICALC = 3).

b. Basic Subprograms

The following FORTRAN subprograms are used in all three SUBROUTINE ANALIZ codes:

1) SUBROUTINE CH75RA--calculates the equivalent blade section chord length ($c_{.75R}$) for the propeller using Table 1 [Ref. 2, p. 252].

2) SUBROUTINE REY75R--calculates the equivalent Reynolds number ($Rn^*_{.75R}$) using equations (3.19) and (3.20).

3) SUBROUTINE COEFSA--calculates the thrust and torque coefficients (K_T and K_Q) through sequential calls to SUBROUTINE CALCKT and SUBROUTINE CALCKQ. The polynomial expressions

(Tables (5) and (6), [Ref. 2]) for these coefficients are contained in SUBROUTINE CALCKT and SUBROUTINE CALCKQ respectively.

4) SUBROUTINE OPWEFF--calculates the open water efficiency (η_o) using equation (3.11).

5) SUBROUTINE JCNA--calculates the constraints on the advance ratio (J) given by equations (4.17) and (4.18).

6) SUBROUTINE REYCNA--calculates the equivalent Reynolds number constraints given by equations (4.11) and (4.12).

7) SUBROUTINE EXTCCN--calculates the constraints on expanded area ratio (A_E/A_O) and equivalent blade section maximum thickness-to-chord ratio ($t^*/c_{.75R}$) given by equations (4.14), (4.15), (4.20) and (4.21).

8) SUBROUTINE DICNUA--calculates the constraint on the propeller diameter (D) given by equation (4.2) using the hull parameter on maximum diameter (D_{lim}).

9) SUBROUTINE CAVCNA--calculates the constraint for cavitation given by equation (4.5) using equation (4.3).

10) SUBROUTINE STRCNA--calculates the constraint for strength given by equation (4.8) using equation (4.9).

H. SUMMARY

The propeller selection problem has now been formulated as a constrained optimization problem which can be solved by COPES/CONMIN. Two items remain for discussion before proceeding to specify the final details pertaining to each SUBROUTINE ANALIZ code and to present numerical examples. These items are:

1) the theory and coding relating to the computation of the propeller's blade weight for the evaluation of the objective function in Design Case No. 3 (OBJ_3).

2) the theory and coding relating to the computation of the minimum required equivalent blade section maximum thickness-to-chord ratio ($t^*/c_{.75\ min}$) for use in the alternative evaluation of the strength constraint given by equation (4.8).

V. PROPELLER BLADE WEIGHT--AN OBJECTIVE FUNCTION

A. INTRODUCTION

In this chapter, the method for the computation of the propeller's blade weight (bldwt), the objective function OBJ, is examined. First, a brief overview on the steps in the computational procedure is presented. The FORTRAN subprogram SUBROUTINE WGTCAL developed from the algorithm is then described. Again, Appendix B contains all subprogram listings.

B. THEORY AND PROCEDURE

Given the material of a propeller, the calculation of the weight of one blade involves nothing more than a volume calculation, a relatively routine task performed by most naval architects/marine engineers. Analagous to the determination of the underwater volume of a ship's hull, the calculation is an integration of blade section profiles' cross-sectional areas over the propeller radius (R).

1. Limits of Integration

Figure (5.1) depicts a side elevation view of a blade and hub, parallel to the propeller shaft axis. The cross-hatched area indicates the trace of the volume to be calculated. In view of equations (3.32) and (3.33), limits of integration are from r = .167R to r = R for Z = 4,5,6 and r = .18R to r = R for Z = 3,7. For convenience, a non-dimensional variable "x" will be defined as:

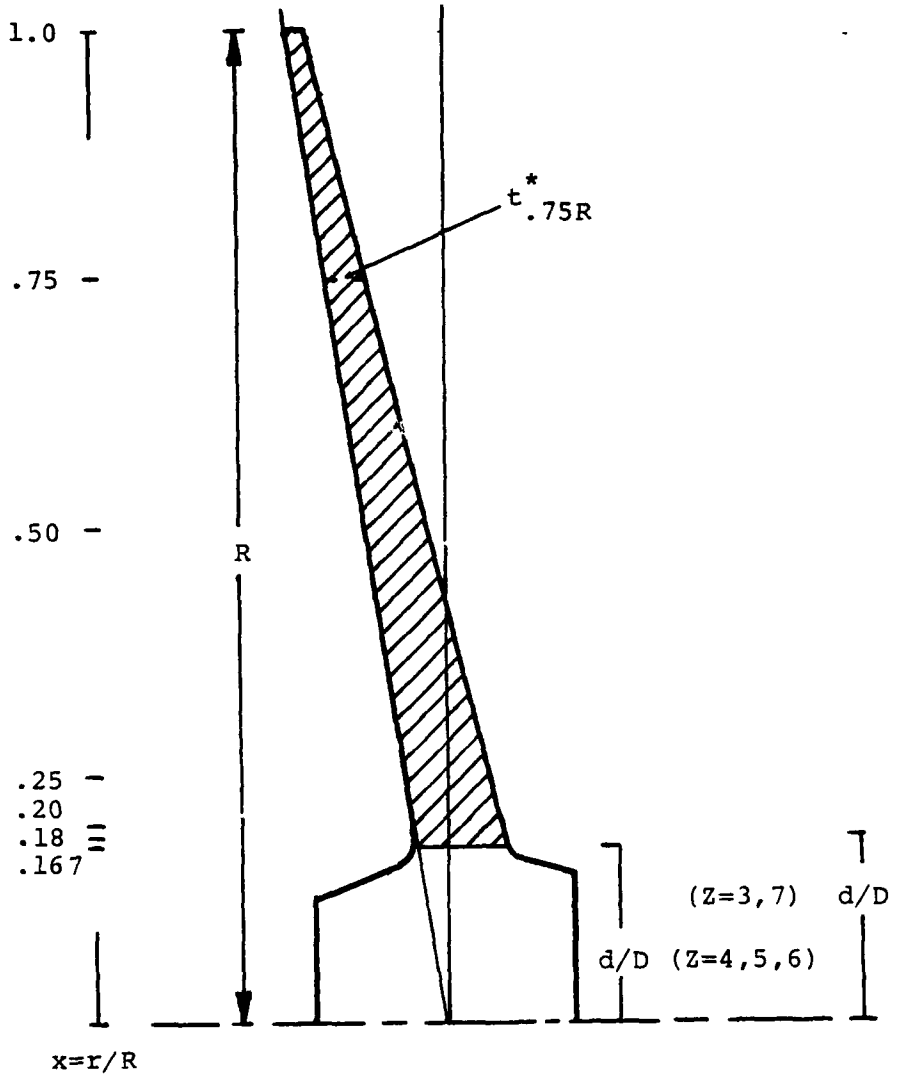


Figure 5.1 Propeller Blade & Hub--Side View

$$x = \frac{r}{R} \tag{5.1}$$

Limits are now expressed as x = .167 or .18 to x = 1.0. Quite obviously, R = (D/2.0).

2. Blade Section Profile

Figure (5.2) depicts an expanded cylindrical blade section in profile view at a given r or x. For the Wageningen B-Screw Series, the profile is defined, geometrically, by a succession of vertical ordinates which specify points along the blade section's profile on the "face" (y_f) and on the back (y_b) with respect to the pitch reference line. At any r = xR, vertical ordinates for "aft" (P < 0) and "fwd" (P > 0) portions of the blade section are determined by:

$$y_{fa} = V_1(t^* - t^*_{te}) \qquad P \leq 0 \tag{5.2}$$

$$y_{ba} = (V_1 + V_2)(t^* - t^*_{te}) + t^*_{te} \qquad P \leq 0 \tag{5.3}$$

and

$$y_{ff} = V_1(t^* - t^*_{\ell e}) \qquad P > 0 \tag{5.4}$$

$$y_{bf} = (V_1 + V_2)(t^* - t^*_{\ell e}) + t^*_{\ell e} \qquad P > 0 \tag{5.5}$$

where:

V_1, V_2 = tabulated values depending on x and P (see Tables (2) and (3), Ref. [2]);

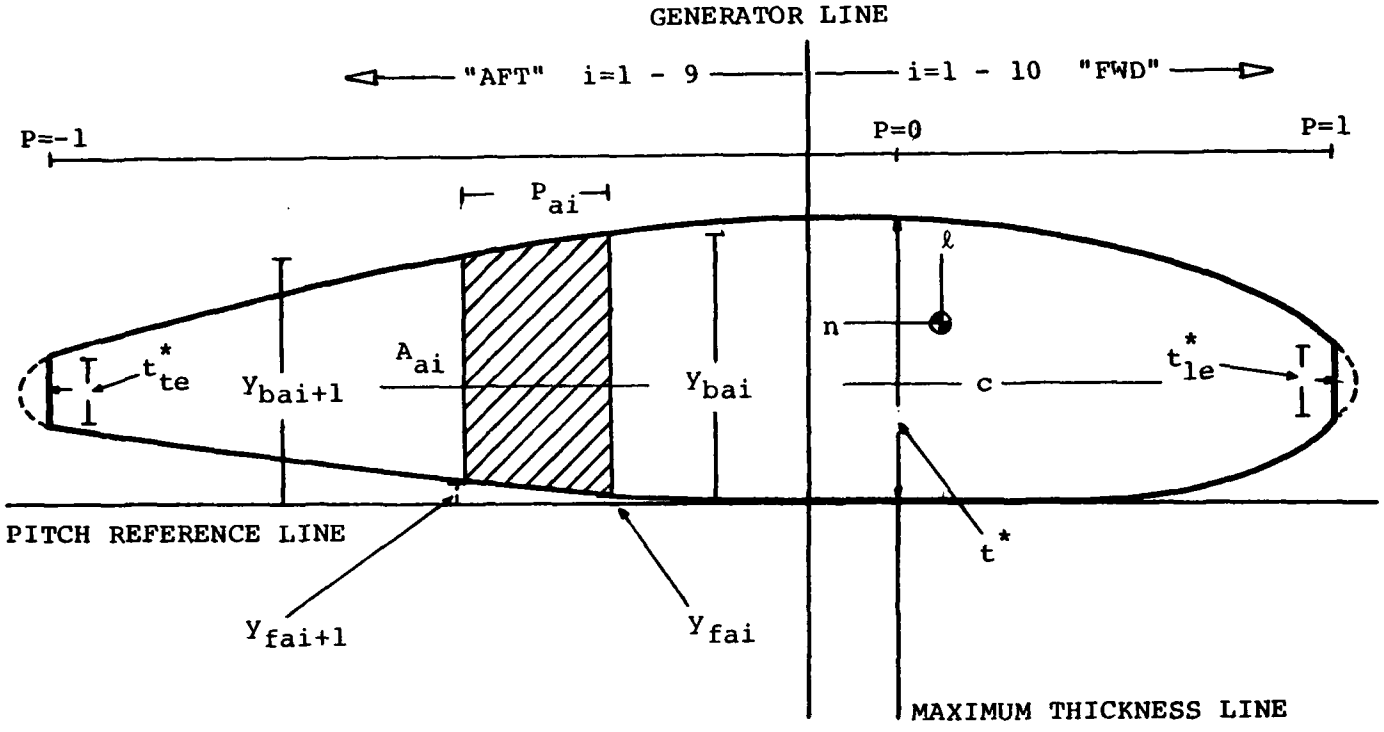


Figure 5.2 Expanded Cylindrical Blade Section--Profile View

t^*_{le} = blade section leading edge thickness (ft);

t^*_{te} = blade section trailing edge thickness (ft).

Units for y_{fa}, y_{ba}, y_{ff} and y_{bf} are feet (ft). For this study, a reasonable assumption is made in that:

$$t^*_{le} = t^*_{te} = (\frac{1}{10})\ t^* \tag{5.6}$$

3. Blade Section Cross-Sectional Area

The cross-sectional area at each x = r/R (A(x)) is determined by:

$$A(x) = \sum_{i=1}^{9} A_{ai} + \sum_{i=1}^{10} A_{fi} \tag{5.7}$$

where

$$A_{ai} = \Delta P_{ai}\{\frac{h_{ai+1} + h_{ai}}{2}\} \tag{5.8}$$

$$h_{ai} = y_{bai} - y_{fai} \tag{5.9}$$

$$h_{ai+1} = y_{bai+1} - y_{fai+1} \tag{5.10}$$

Expressions for A_{fi}, h_{fi} and h_{fi+1} follow in similar fashion.

Values for y_{fai} and y_{bai} are determined at 9 points along the "aft" portion of a given blade section's chord (c): values of y_{ffi} and y_{bfi} are determined at 10 points along the

"fwd" portion. The values for ΔP_{ai} and ΔP_{fi} are fractional values of the blade section's chord length (c) at radius r = xR as determined from Tables (2) and (3) in Reference [2]. The units for A(x) are square feet (ft^2). Units for h_{ai}, h_{ai+1}, h_{fi}, h_{fi+1}, c, ΔP_{ai} and ΔP_{fi} are feet (ft).

4. Volume Integration

The blade volume (bldvol) is finally determined by using Simpson's Rule for integration of A(x) along the non-dimensional radius x using appropriate limits.

5. Blade Weight

Once the blade volume (bldvol) is calculated, the weight (bldwt) is determined by:

$$bldwt = bldvol \cdot wd \cdot 1728 \qquad (5.11)$$

where:

bldvol = volume of one blade (ft^3);

wd = material weight density (lbf/in^3).

Weight Density (wd) depends on blade material (promat). Table (II) lists appropriate values.

C. CODING

SUBROUTINE WGTCAL is the main subprogram for the blade weight calculation. It, in turn, calls the following FORTRAN subprogram for various calculations:

1) SUBROUTINE TDIST--generates, at specified radius values, a distribution of blade section maximum thicknesses (t*).

2) SUBROUTINE BLDPRP--generates, at specified radius values (i.e., r = .167R or .18R, .2R, .3R, .4R, ..., .9R, 1.0R), various "blade section properties", one of which is a blade section's cross-sectional area given by equation (5.7). Other properties which are determined (for later use in direct stress computations) include blade section chord lengths and centroids and "critical point" locations as defined in Chapter VI.

3) SUBROUTINE BLDVOL --performs a Simpson's Rule integration for the propeller blade volume (bldvol) using blade section cross-sectional areas generated in SUBROUTINE BLDPRP. The blade weight (bldwt) is computed as a final step in the main subprogram SUBROUTINE WGTCAL.

Examination of the codes in Appendix B reveals extensive use of common blocks for passing data from one subprogram to another. Comment cards provide a full definition of all common blocks as well as a description of the task being performed at various points in a given subprogram.

D. SUMMARY

The coding developed for this study is, admittedly, not very compact and efficient. However, the intention has been to write all codes with sufficient documentation in order to facilitate the reader's understanding of the algorithms employed as well as to make the author's debugging work easier.

VI. THICKNESS-TO-CHORD RATIO--A DESIGN CONSTRAINT

A. INTRODUCTION

The purpose of this chapter is to examine the development of an algorithm that will be used to determine the minimum required equivalent blade section maximum thickness-to-chord ratio used in equation (4.8). The formulation is based upon the method developed by Dr. Karl E. Schoenherr [Ref. 8] in 1963. After a review of the past and present methods employed in propeller strength analysis is conducted, a description of the Schoenherr model and a list of the assumptions used with that model is presented. Then, a brief restatement of his model's equations which are used in the algorithm is followed by a derivation of the author's modifications to the Schoenherr method. The chapter is completed by conducting a review of the theory and coding employed by the algorithm.

The principal reference which is cited throughout this chapter is, again, Reference [8]. The reader is encouraged to review this reference for further details.

B. PROPELLER STRENGTH ANALYSIS--A HISTORICAL REVIEW

Marine propeller blades present a special class of structural problem. That problem lies in the difficulty of describing a blade design in simple mathematical terms for subsequent analysis through various means. Until the "finite element method era", analytical methods, including the one

[Ref. 8] adapted for this study, relied heavily on practical experience of the propeller designer and semi-theoretical considerations. Analysis by these methods provided a criterion of stress rather than actual computation of stresses. These methods for predicting blade stresses were developed by using "beam" theory or "shell" theory.

The use of elementary beam theory in propeller strength analysis was first adopted by Taylor [Ref. 22]. He treated a blade as a cantilever beam attached to the propeller hub and loaded by thrust and torque forces distributed linearly over the propeller radius. His approach is often deemed a "modified beam theory" because he chose to calculate the direct stresses using the moment of inertia properties of expanded cylindrical blade sections with neutral axis parallel to the nose-tail (pitch-reference) line or chord of that expanded section. Reasonable estimates of stresses along the blade surface were achieved for the unraked, unskewed and narrow-bladed propellers of his time.

As propellers "modernized" and became skewed and wider with increasing rake (mostly aft), modifications, improvements and alternatives to Taylor's theory were developed. Principally, modifications by Rosingh [Ref. 23] and Hancock [Ref. 24] proposed using moment of inertia properties of a blade section that was normal to the generating line of the axially projected blade outline. Romson [Ref. 25] later improved Taylor's theory for application to wide-bladed

propellers. Morgan [Ref. 26] provided an improved method for calculating the geometric properties of "modern" airfoil-shaped blade sections. Aernoldus and Keyser's [Ref. 27] "quasi-static" modeling of the propeller blade allowed for additional consideration to stresses induced by centrifugal loading of the raked and skewed blade. The beam theory approaches to propeller blade stress analysis culminated, for all practical purposes, with Schoenherr's work [Ref. 8] in 1963.

Alternatives to Taylor's beam theory approach, prior to 1963, consisted of the application of "shell" theory to the propeller blade strength problem. This approach was first proposed by Conn [Ref. 28] and subsequently formulated by Cohen [Ref. 29] who modeled the blade as a helicoidal shell with variable thickness and infinite width. "Shell Theory" was utilized again in experimental studies by Connolly [Ref. 30] who, like his predecessors, was also forced into making an assumption about the behavior of the displacements of the blade sections (i.e., constant displacements normal to the constant pitch blade at each fractional radius distance from the hub) beyond usual assumptions of shell theory. Essentially, his experimental results on one specific propeller contradicted the computational values. Attempts at a generalized numerical solution to Connolly's equations appeared in 1963 [Ref. 31] and 1964 [Ref. 32]. In 1968, Atkinson [Ref. 33], compared Connolly's results with currently

adopted cantilever beam methods and found, based on the inconsistency of results, that it was not possible to recommend one method over the other in the blade strength design procedure; another approach was needed.

Commenting on Atkinson's paper at that time, Sontvedt [Ref. 34] pointed out that, in view of these inconsistencies, the only approach to blade strength analysis which did not require very broad assumptions was the finite element technique. Developments in the method at that time were providing a new and powerful tool for structural analysis. The propeller blade was just another application. Genalis [Ref. 35] developed codes for the determination of displacements and stresses in a blade under hydrodynamic loads using the FEM technique and modeling the blade as a shell, a 3-D element mesh of tetrahedrons and rectangular prisms and, finally, a composite of shell and 3-D elements. As an aside, a finite "difference" solution to Connolly's analytical equations was proposed in 1972 [Ref. 36]. In 1973, Atkinson [Ref. 37] reported the application of both hydrodynamic and centrifugal loads to a blade modeled by a thin-shell triangular mesh and a thick-shell parabolic and cubic curved element mesh. The results of the triangular element were considered unsatisfactory. Another use of the thin-shell triangular element was reported by Sontvedt [Ref. 34] in 1974 using the SESAM-69 code [Ref. 38].

The need to model the blade correctly near the hub, where root stresses are usually critical, necessitated the

consideration of 3-D elements in lieu of thick/thin-shell elements [Refs. 39,40]. The use of the 4- and 10-noded tetrahedral element (i.e., TET-4, TET-10 respectively) to construct a blade mesh was conducted by Beek [Refs. 41,42]. He observed that improved accuracy of stress values, achieved by the use of these meshes, were overshadowed somewhat by the extensive storage capacity required for each analysis. Another "natural" improvement, from a geometrical standpoint, appeared in 1978. A general 3-D curved isoparametric element was incorporated in a computer code [Ref. 43] developed by Ma based on his previous formulation work [Ref. 44].

The finite element approach will continue to grow in use in propeller blade strength analysis with each successive improvement made to the basic elements which are used in the mesh generation of the blade. But, until the computer storage problem is resolved to the point where one mesh generation and subsequent stress analysis of one particular blade becomes a minor processing task, the basic analytical techniques will continue to be a meritable "check" [Ref. 45] in the preliminary (or conceptual) phase of propeller selection/ design. In this context, the method formulated by Schoenherr and his colleagues twenty years ago is considered for adoption in determining a minimum required blade section maximum thickness-to-chord ratio.

C. SCHOENHERR'S METHOD

1. Background

Schoenherr's method is applicable to preliminary (or, conceptual) propeller selection problems because it employs an assumed thrust and torque force loading distribution for the propeller blade. This assumption is made at this stage of the ship's design because the exact wake velocity distribution at the propeller race is generally not known.

Also, his method is applicable to propellers represented by the Wageningen B-Screw Series because the blades of these propellers meet Schoenherr's criteria for the blade types covered by his formulation. Specifically, B-Screw Series blades have:

1) a small constant rake angle of 15° over the entire blade radius;

2) a constant pitch distribution over the propeller radius with the exception of the Z = 4 propeller whose pitch is slightly reduced near the hub;

3) mild skew;

4) linear distribution of blade section maximum thickness over the radius of the blade;

5) aerfoil profile qualities where the nose-tail line or the chord of the blade section is approximately parallel to the pitch reference line.

2. The Blade Model

Schoenherr models the propeller blade as a cantilever beam with unsymmetrical and variable area cross sections subjected to loading distributions of hydrodynamic and centrifugal forces. The following additional assumptions apply:

1) Flexure theory applies. This subsequently implies the following: a) plane cross sections remain plane under load, b) Hooke's Law is valid, c) the blade material is homogeneous and isotropic, d) fibers are free to extend and contract independently of adjacent fibers, and e) stresses at a point arising from various forces superimpose.

2) Shearing stresses and their effects are neglected. Only the direct stresses on a strength section are taken into account.

3) The strength sections are taken to be the expanded cylindrical blade sections at various radial locations.

4) The neutral axes of a strength section are straight lines passing through the centroid of the expanded cylindrical blade section and are parallel and normal, respectively, to the pitch reference line, and therefore, the chord, at each blade section.

5) Bending Moments are applied in two planes which are mutually perpendicular to each other. One plane is normal to the pitch-reference line (and chord) of the strength section; the other is parallel.

6) The angle between the principal axes of inertia and the neutral axes is zero.

Using this model and assumptions, Schoenherr applies the following formula for the evaluation of the direct fiber stress ($[\sigma_o]$) in a blade section at a radius $r = r_o$:

$$[\sigma]_o = \frac{[M]_{no}\, u_o}{I_{no}} + \frac{[M]_{\ell o}\, w_o}{I_{\ell o}} + \frac{[F_c]_o}{A(x_o)} \qquad (6.1)$$

where:

$[M]_{no}$, $[M]_{\ell o}$ = resultant bending moments in planes normal ($[M]_{no}$) and parallel ($[M]_{\ell o}$ to the strength section's chord at $r = r_o$ (ft-lbf);

$[F_c]_o$ = centrifugal force acting normal to the plane of the strength section at $r = r_o$ and resulting from the centrifugal acceleration of the remaining blade element mass above that strength section (lbf);

u_o, w_o = coordinates of a point on the strength section's periphery with respect to that section's neutral axes system (ℓ-n system) (ft);

$A(x_o)$ = strength section's cross-sectional area (ft^2);

$I_{\ell o}$ = moment of inertia of the strength section with respect to the "ℓ" axis (ft^4);

I_{no} = moment of inertia of the strength section with respect to the "n" axis (ft^4);

x_o = non-dimensional radius given by $x_o = r_o/R$.

Since equation (6.1) indicates that the direct fiber stress is greatest at points on the periphery of the strength section, Schoenherr selects to examine four "critical points"

on the periphery where the fiber stress is likely to be a maximum. These points are designated as (1), (2), (3) and (4) on Figure (6.1) and are specified by coordinates (u1,w1), (u2,w2), (u3,w3) and (u4,w4) respectively in the "ℓ-n" reference system.

The values for $[M]_{no}$ and $[M]_{\ell o}$ are determined by the following relation:

$$[M]_{no} = [M_p]_{no} + [M_{cb}]_{no} \tag{6.2}$$

$$[M]_{\ell o} = [M_p]_{\ell o} + [M_{cb}]_{\ell o} \tag{6.3}$$

where:

$[M_p]_{no}$ = total bending moment due to hydrodynamic loading acting in a plane normal to a strength section's chord at $r = r_o$ (ftlbf);

$[M_p]_{\ell o}$ = total bending moment due to hydrodynamic loading acting in a plane parallel to a strength section's chord at $r = r_o$ (ftlbf);

$[M_{cb}]_{no}$ = total bending moment due to centrifugal loading acting in a plane normal to a strength section's chord at $r = r_o$ (ftlbf);

$[M_{cb}]_{\ell o}$ = total bending moment due to centrifugal loading acting in a plane parallel to a strength section's chord at $r = r_o$ (ftlbf).

3. Bending Moments Due to Hydrodynamic Loading

The derivations of $[M_p]_{no}$ and $[M_p]_{\ell o}$ follow directly from Part I of Schoenherr's paper [Ref. 8: p. 83-89] and,

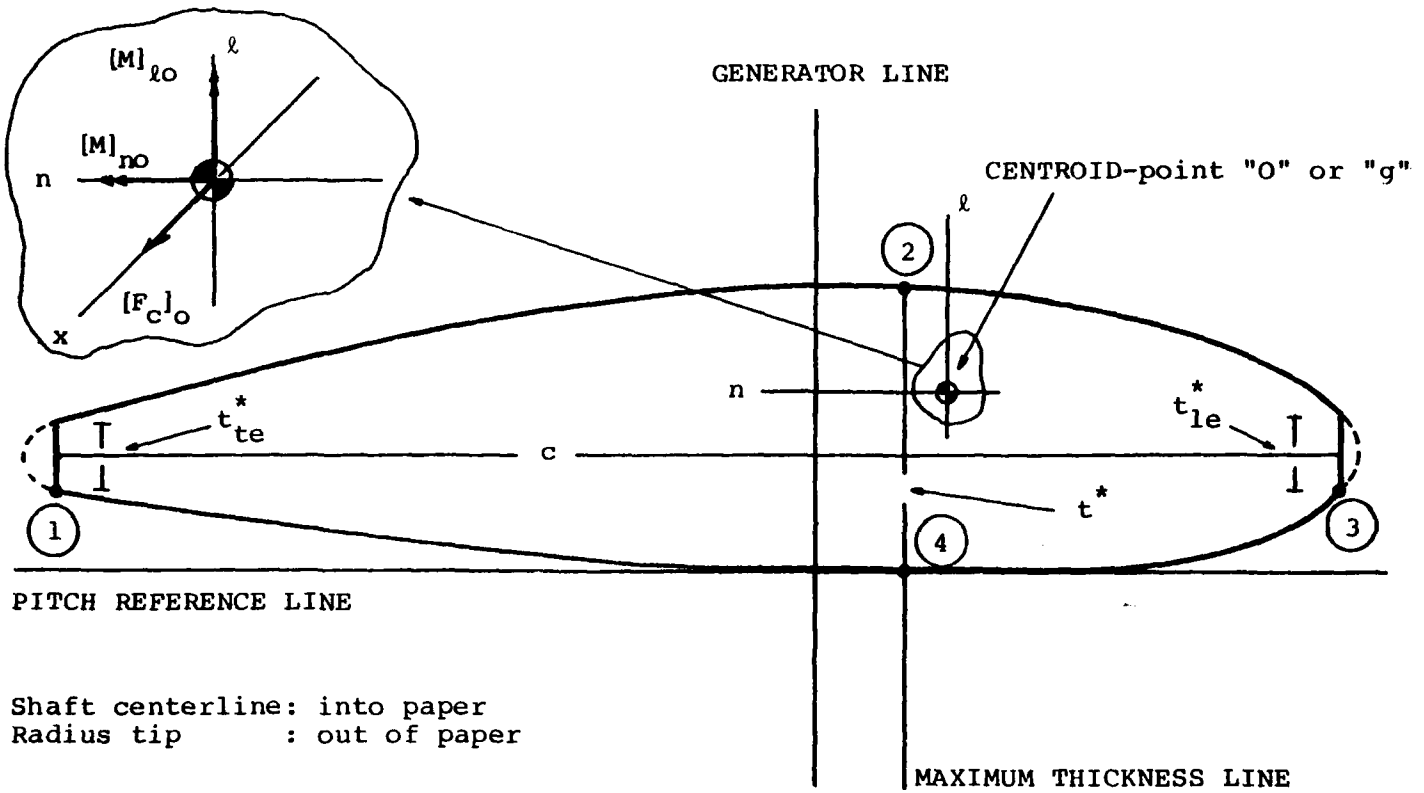


Figure 6.1 Strength Section at $r = r_o$

therefore, only key equations will be restated. References to equations which contain no decimal point apply to equations as numbered in his paper.

Thrust and torque force are components of the hydrodynamic "lifting" force acting on a blade. Using an assumed non-linear distribution of thrust along the blade radius given by equation (2), Schoenherr derives the following expression for the bending moment due to thrust ($[M_t]_o$) which acts at a blade section located at ratius $r = r_o$:

$$[M_t]_o = \frac{TR}{Z} \cdot \frac{\phi_2(x_o)}{\phi_1(x_h)} \qquad (6.4)$$

where:

T	=	propeller thrust (lbf);
R	=	propeller radius (ft);
Z	=	no. of blades;
$\phi_2(x_o), \phi_1(x_h)$	=	functions of non-dimensional radius x evaluated at $x_o = r_o/R$ and $x_h = 0.2$ and given by equations (4) and (9).

For the bending moment due to torque ($[M_q]_o$) which acts at a blade section located at radius $r = r_o$, Schoenherr derives the following:

$$[M_q]_o = \frac{Q_P}{Z} \cdot \frac{\psi_2(x_o)}{\phi_1(x_h)} \qquad (6.5)$$

where:

Q_P = propeller torque (ft-lbf);

Z = no. of blades;

$\psi_2(x_o), \phi_1(x_h)$ = functions of non-dimensional radius x evaluated at $x_o = r_o/R$ and $x_h = 0.2$ and given by equations (19) and (4).

Figure (6.2) depicts the component resolution for $[M_P]_{no}$ and $[M_P]_{\ell o}$ which results when equations (6.4) and (6.5) are imposed at a strength section at $r = r_o$ which has a pitch angle β_o. The following relations are derived as equations (42) and (43) in Schoenherr's paper:

$$[M_P]_{no} = [M_t]_o \cos \beta_o + [M_q]_o \sin \beta_o \qquad (6.6)$$

$$[M_P]_{\ell o} = [M_t]_o \sin \beta_o - [M_q]_o \cos \beta_o \qquad (6.7)$$

4. Force and Bending Moments Due to Centrifugal Loading

The derivation and expressions contained in this section constitute the author's modifications to the formulation in Part II of Schoenherr's paper. In Part II, Schoenherr's derivations for $[M_{cb}]_{no}$ and $[M_{cb}]_{\ell o}$ are formulated for computation using a propeller drawing. This follows from the fact that his method, which was funded by the American Bureau of Shipping, was intended to be used as that classification society's "designer's check" on adherence to the Bureau's strength criteria from a propeller blueprint. To evaluate the direct fiber stresses from equation (6.1) for the Wageningen B-Screw Series in accordance with Schoenherr's

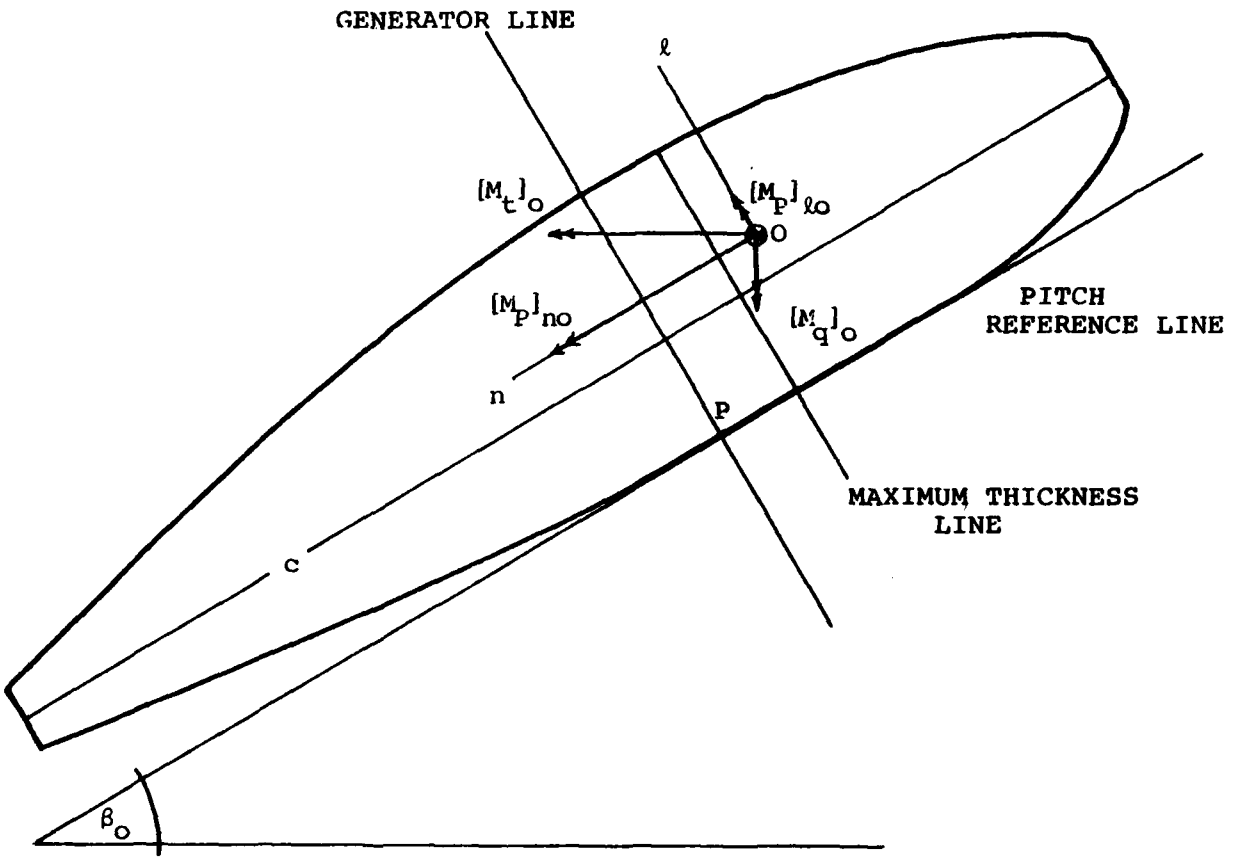


Figure 6.2 Bending Moments due to Thrust and Torque

method, $[M_{cb}]_{no}$ and $[M_{cb}]_{\ell o}$ must be evaluated from expressions derived from the available information on blade section profiles and other geometric characteristics which are contained in Reference [2] and previously used in Chapter V.

Consider Figure (6.3) where the centrifugal force $[C_F]_o$ of a blade element above a blade section at $x = x_o = r_o/R$ acts in a radial direction from the shaft centerline. Its line of action passes through point "N", which is on the same cylindrical surface as the blade section at $x = x_o = r_o/R$, and through point "G", which is the center of gravity of the blade element above the blade section at $x = x_o = r_o/R$. From the figure, the following expression is derived:

$$[C_F]_o = [C_F]_o \cos \zeta(x_o) + [C_F]_o \sin \zeta(x_o) \qquad (6.8)$$

$[C_F]_o$ is shifted to point "N" and is decomposed into components $[C_F]_o \cos \zeta(x_o)$ and $[C_F]_o \sin \zeta(x_o)$. The entire cylindrical surface in which the blade section at $x = x_o = r_o/R$ and point "N" lie is now expanded into a flat plane for further consideration (see Figure (6.4)). In this configuration, $[C_F]_o \cos \zeta(x_o)$ is normal to this flat plane while $[C_F]_o \sin \zeta(x_o)$ lies in this plane.

Let point "O" be the location of the blade section's neutral axes system (i.e., the ℓ-n system). Then, the forces and moments due to the centrifugal reaction of the blade element above this section act at point "O" and are given by:

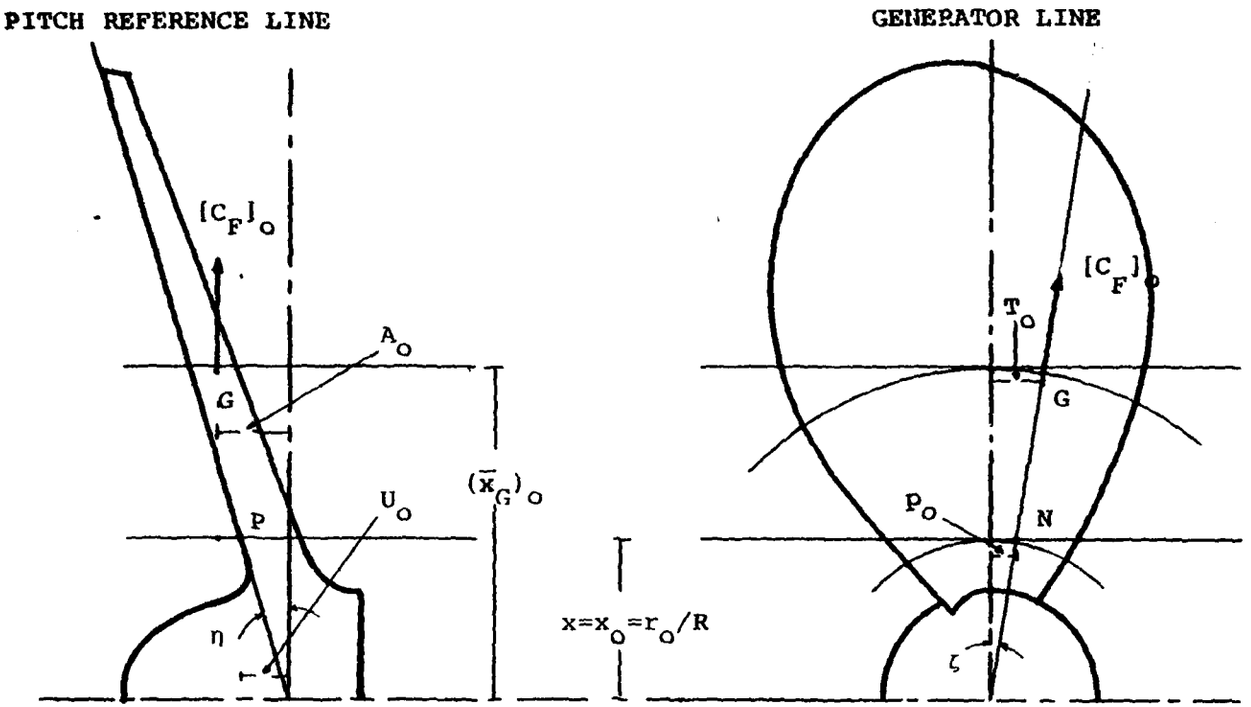


Figure 6.3 Center of gravity "G" and intersection point "N"

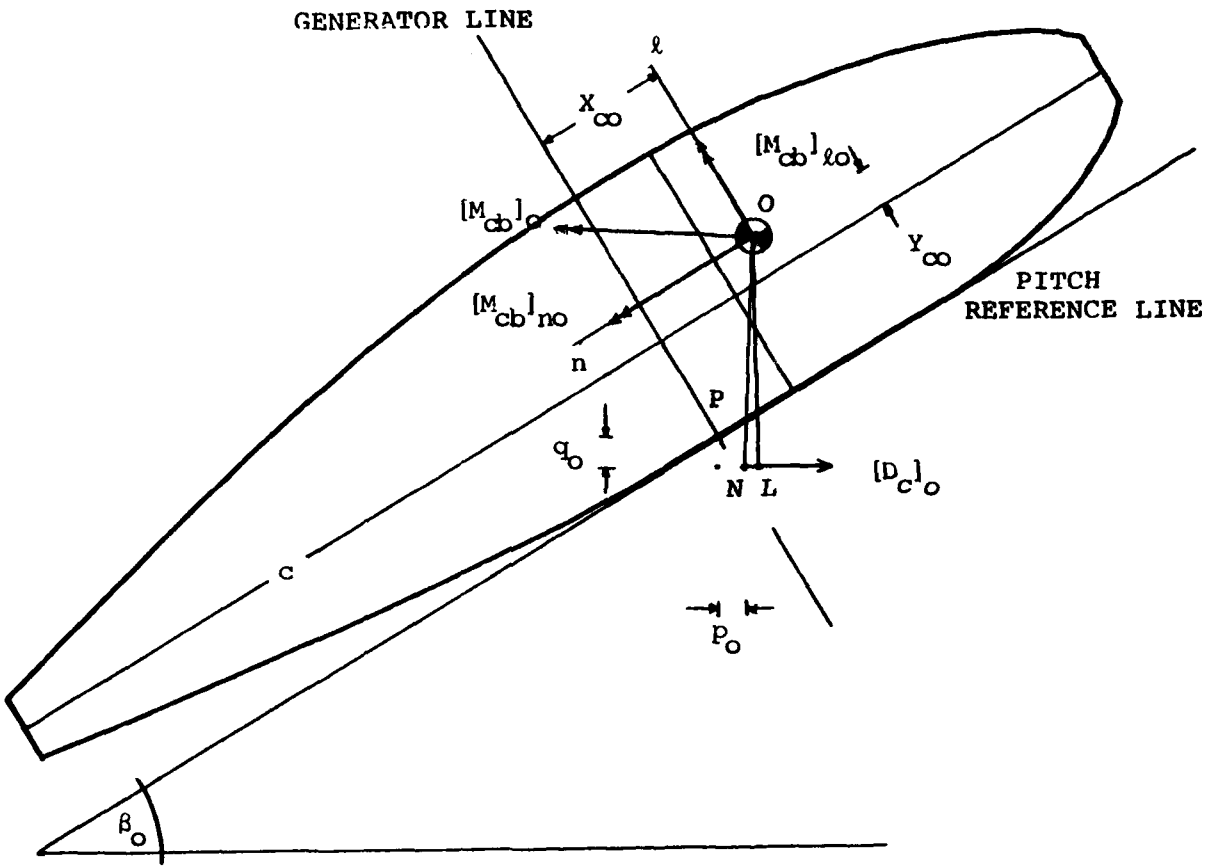


Figure 6.4 Internal Loading on a Blade Section at $x = x_o = r_o/R$

$$[F_c]_o = [C_F]_o \cos\zeta(x_o) \tag{6.9}$$

$$[D_c]_o = [C_F]_o \sin\zeta(x_o) \tag{6.10}$$

$$[M_{cb}]_o = [F_c]_o \cdot \overline{NO} \tag{6.11}$$

$$[M_{cw}]_o = [D_c]_o \cdot \overline{LO} \tag{6.12}$$

where:

$[F_c]_o$ = direct force, due to centrifugal action, acting on the blade section located at $x = x_o = r_o/R$;

$[D_c]_o$ = shear force, due to centrifugal action, acting on the blade section located at $x = x_o = r_o/R$;

$[M_{cb}]_o$ = bending moment at point "O" imposed by $[F_c]_o$ acting through point "N";

$[M_{cw}]_o$ = torsional moment at point "O" imposed by $[D_c]_o$ acting through point "N".

Since Schoenherr's method does not consider shear forces and their effects, $[D_c]_o$ and $[M_{cw}]_o$ will not be considered in this modification. However, $[F_c]_o$ and $[M_{cb}]_o$ must now be computed for each blade section along the propeller's radius in order to account for their contributions to equations (6.2), (6.3) and, finally, in equation (6.1).

The computation is derived as follows. Consider Figure (6.4). Again, $[F_c]_o$ acts through point "N" and is normal (outward) to the plane of the figure. $[M_{cb}]_o$ is now resolved into components of the ℓ-n axes system as follows:

$$[M_{cb}]_{no} = [C_F]_o \cos \zeta(x_o) \{p_o \sin \beta_o + q_o \cos \beta_o + Y_{co}\} \quad (6.13)$$

$$[M_{cb}]_{\ell o} = [C_F]_o \cos \zeta(x_o) \{q_o \sin \beta_o - p_o \cos \beta_o + X_{co}\} \quad (6.14)$$

where:

β_o = pitch angle of the blade section at $x = x_o = r_o/R$;

X_{co} = distance of the blade sections centroid from the generator line (ft);

Y_{co} = distance of the blade section's centroid from the pitch reference line (ft);

q_o = distance to point "N" from point "P" parallel to the shaft axis at $x = x_o = r_o/R$ (ft);

p_o = distance to point "N" from point "P" perpendicular to the shaft axis at $x = x_o = r_o/R$ (ft).

The quantity β_o is found by the relation:

$$\tan \beta_o = \frac{1}{\pi} \cdot (P/D)_o \quad (6.15)$$

For the Wageningen B-Screw Series, $(P/D)_o$ is a constant along R except for propellers with Z = 4.

The quantity $[C_F]_o$ is computed from the relation:

$$[C_F]_o = 1728 \cdot \frac{wd\ V_o}{acg} \cdot (2\pi n_p)^2 \cdot R \cdot (\bar{x}_G)_o \quad (6.16)$$

where:

V_o = volume of the blade element above the blade section at $x = x_o = r_o/R$ (ft^3);

acg = 32.174 ft/sec^2;

wd = material weight density (lbf/in^3);

n_p = propeller revolution rate (rps);

$(\bar{x}_G)_o$ = non-dimensional radial position of "G" for the blade element above the shaft axis;

R = propeller radius (ft).

At this point, only five quantities remain to be determined for the evaluation of the expressions of equations (6.10), (6.13) and (6.14). They are:

1) $\cos \zeta(x_o)$
2) p_o
3) q_o
4) $(\bar{x}_G)_o$
5) V_o

These quantities are determined by integration over the blade element above the blade section, located at $x = x_o = r_o/R$, from $x = x_o$ to $x = 1.0$.

The values for p_o and q_o will vary with the location of "G" (from Figure (6.3)) which depends on x. Consider a radially thin slice of the blade element above the blade section, located at $x = x_o = r_o/R$ (see Figure (6.5)). This thin "slice" is located at a non-dimensional distance x from the shaft centerline where $x_o < x < 1.0$. Figure (6.6) depicts this section expanded onto a plane. Let "g" be the centroid of that "slice". If x_g is the distance from the generator

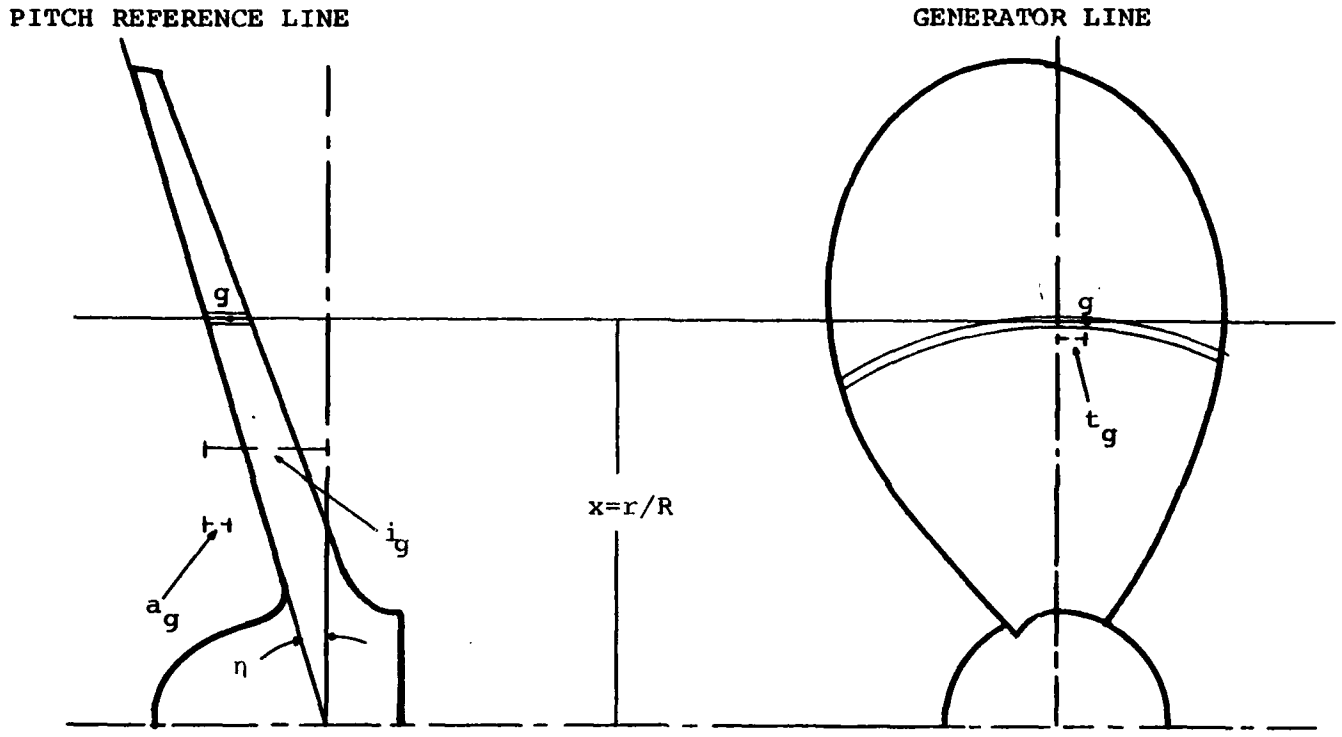


Figure 6.5 Position of "g" of a Blade Section "Slice" at x = r/R

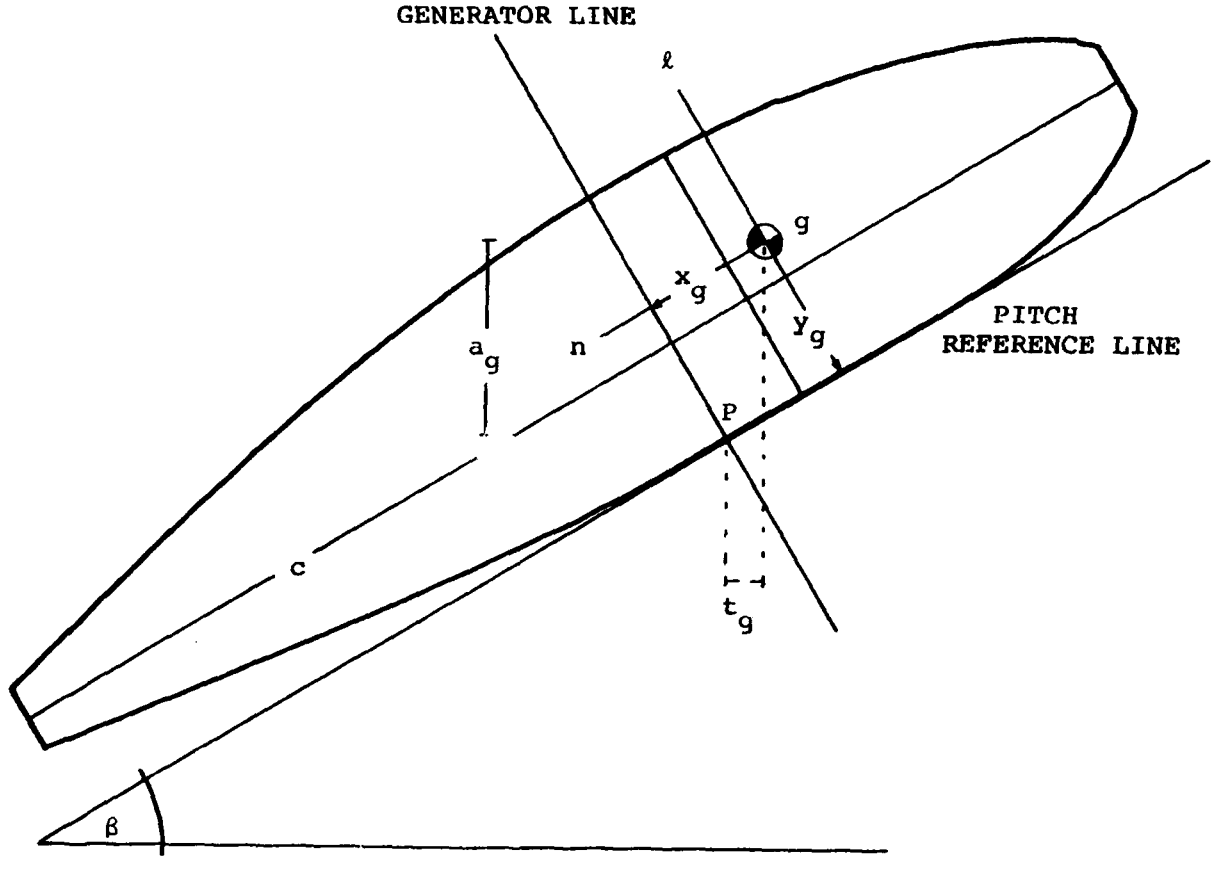


Figure 6.6 Coordinates of centroid "G" of any Blade Section

line to "g" in feet and y_g is the distance from the pitch reference line in feet, then, from Figures (6.5) and (6.6), the following relations apply:

$$i_g = x\ R \tan \eta \tag{6.17}$$

$$i_g - a_g = i_g - x_g \sin \beta_g - y_g \cos \beta_g \tag{6.18}$$

$$t_g = x_g \cos \beta_g - y_g \sin \beta_g \tag{6.19}$$

where:

η = rake angle at x;

x_g = distance of "g" from point "P" parallel to the shaft axis (ft);

y_g = distance of "g" from point "P" perpendicular to the shaft axis (ft).

For the Wageningen B-Screw Series, rake angle η is a constant 15° everywhere along the radius R.

Now, to compute the volume of the blade element above the blade section located at $x = x_o = r_o/R$, the following expression is used:

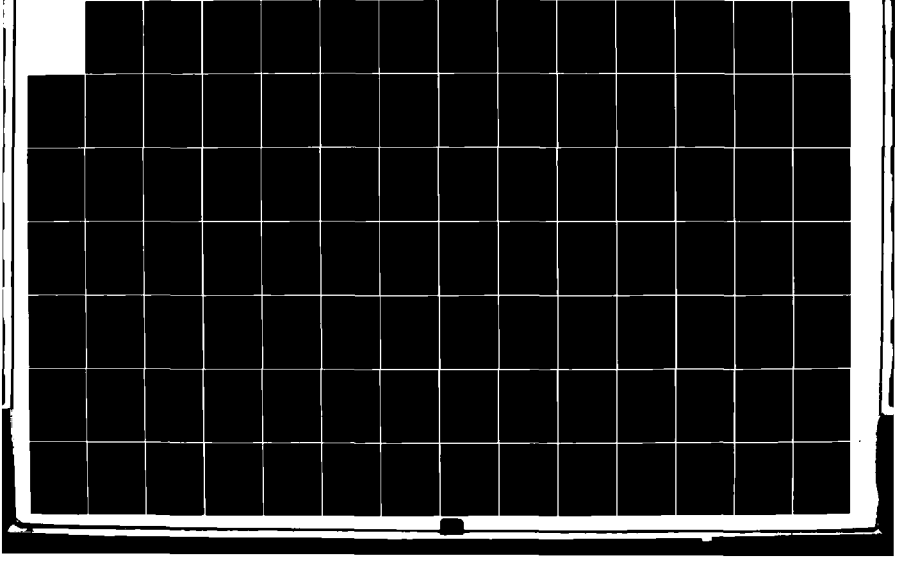
$$V_o = \int_{x=x_o}^{1} RA(x)\ dx \tag{6.20}$$

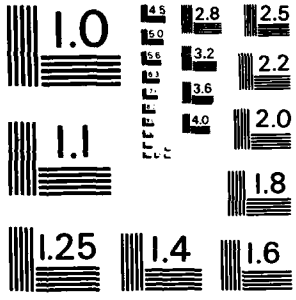
To compute the non-dimensional radial position of "G" for the blade element above a blade section located at $x = x_o = r_o/R$, the following expression is used:

AD-A132 414 PRELIMINARY PROPELLER SELECTION USING THE WAGENINGEN B-SCREW SERIES AND A GENERAL PURPOSE NON-LINEAR OPTIMIZER(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA

2/4

UNCLASSIFIED M P SMITH JUN 83 F/G 13/10 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

$$(\bar{x}_G)_o = \frac{\int_{x=x_o}^{1} A(x)\, x\, dx}{\int_{x=x_o}^{1} A(x)\, dx} \qquad (6.21)$$

To compute the tangential position of "G" for the blade element above a blade section located at $x = x_o = r_o/R$, the following expression is used:

$$T_o = \frac{\int_{x=x_o}^{1} A(x)\, t_g\, dx}{\int_{x=x_o}^{1} A(x)\, dx} \qquad (6.22)$$

And, finally, to compute the axial position of "G" for the blade element above a blade section located at $x = x_o = r_o/R$, the following expression is used:

$$A_o = \frac{\int_{x_o}^{1} A(x)\,(i_g - a_g)\, dx}{\int_{x_o}^{1} A(x)\, dx} \qquad (6.23)$$

Using the values just determined for $(\bar{x}_G)_o$, T_o and A_o, the following expressions are used to evaluate p_o and q_o:

$$p_o = \frac{x_o}{(\bar{x}_G)_o}\, T_o \qquad (6.24)$$

$$q_o = A_o - x_o \tan \eta \tag{6.25}$$

The expression for $\cos \zeta(x_o)$ follows:

$$\cos \zeta(x_o) = \frac{p_o}{x_o R} \tag{6.26}$$

The formulation is now complete. Equations (6.10), (6.13) and (6.14) can now be evaluated for any blade section located at $x = x_o = r_o/R$. From here, equations (6.2) and (6.3) are evaluated. Finally, using the results from these equations and equation (6.9), equation (6.1) can be evaluated for the four points, specified by coordinates (u1,w1), (u2,w2), (u3,w3) and (u4,w4), at any location $x = x_o = r_o/R$.

From the development discussed in Chapter V, the values for $A(x)$, x_g, y_g, I_{no} and $I_{\ell o}$ are readily available.

D. ALGORITHM FOR THE CONSTRAINT

1. Theory

Schoenherr's formulation with the modifications just derived can be used in determining the minimum required equivalent blade section maximum thickness-to-chord ratio ($(t^*/c)_{.75R\ min}$) for use in the constraint $G_{11}(\bar{X}) \leq 0$ given by equation (4.8). The procedure employed is as follows:

1) assume an initial value for $(t^*/c)_{.75R\ min}$ using equation (3.21);

2) increase this value by a small amount;

3) using $(t^*/c)_{.75R\ min}$ obtained from step (2), generate a distribution of minimum required blade section thicknesses (t^*_{min}) for blade sections at specified points along the propeller radius, say at r = .2R, .3R, .4R, .5R, .6R, .7R, .8R and .9R;

4) determine all blade section properties to include: a) cross-sectional area, b) chord length, c) centroid location, d) moments of inertia with respect to the principal axes system (i.e., ℓ-n system), e) coordinate values for the four critical points defined in the previous section;

5) compute the hydrodynamic bending moment components $[M_P]_{no}$ and $[M_P]_{\ell o}$ at radius locations just specified;

6) compute the values of the centrifugal force $[F_c]_o$ and the bending moment components $[M_{cb}]_{no}$ and $[M_{cb}]_{\ell o}$ acting on blade sections at radius locations just specified;

7) calculate the direct fiber stresses at all four critical points for all radius locations specified in step (3);

8) check the following condition on the calculated fiber stress at all four critical points at all specified radius locations using:

$$[\sigma]_o \leq 144 \cdot S_c \qquad (6.27)$$

9) if the maximum allowable stress (S_c) for the material is exceeded, then return to step (2) and repeat. Otherwise, proceed to next step.

10) since the minimum required equivalent blade section maximum thickness-to-chord ratio assumed in step (2) has produced blade sections of adequate strength, evaluate the constraint given by equation (4.8).

2. Coding Details

The algorithm just outlined is incorporated into the main FORTRAN subprogram SUBROUTINE STRCNK. This subprogram, in turn, executes the algorithm through sequential calls to other key FORTRAN subprograms. These subprograms are listed as follows:

1) SUBROUTINE TDIST--accomplishes step (3); generates, at specified radius values, a distribution of minimum required blade section maximum thicknesses (t^*_{min}) for the assumed value of $(t^*/c)_{.75R\ min}$);

2) SUBROUTINE BLDPRP--accomplishes step (4); described previously in Chapter V;

3) SUBROUTINE HYDLD--accomplishes step (5); computes the hydrodynamic bending moment components, given by equations (6.6) and (6.7), at specified radius locations;

4) SUBROUTINE CNFGLD--accomplishes step (6); computes the centrifugal force and bending moments, given by equations (6.9), (6.13) and (6.14) respectively, at specified radius locations;

5) SUBROUTINE SIGNDS--accomplishes step (7); computes direct fiber stresses, given by equation (6.1), for all four critical points at every specified radius location.

During the remaining steps of SUBROUTINE STRCNK, the condition on allowable stress, given by equation (6.27), is checked at all critical points of blade sections located at specified radius locations (again, r = .2R, .3R, .4R, .5R, .6R, .7R, .8R and .9R). The final calculation made is that for the constraint given by equation (4.8).

Again, extensive use of common blocks, for passing data from one subprogram to another, is apparent upon examination of the codes just cited. Comment cards are used throughout.

E. SUMMARY

The end of this chapter marks the completion of all prerequisite background and formulation discussions on the application of COPES/CONMIN to propeller selection problems involving the Wageningen B-Screw Series. From this point, each specific Design Case can now be solved as an optimization problem.

VII. DESIGN CASE NO. 1--PROGRAMMING AND COMPARISONS

A. INTRODUCTION

In this chapter, COPES/CONMIN is used in the solution of propeller selection problems which use the "thrust" approach. First, the thrust approach to the propeller selection problem is formulated. Then, a review of a previous author's solution to this problem is presented. Four variations to this propeller selection problem are solved by COPES/CONMIN. The chapter is completed with a presentation and discussion of the results from the four variations.

B. THRUST APPROACH FORMULATION

1. Design Vector $\overline{XI}$

As previously pointed out at the conclusion of Chapter III, Design Case No. 1 constitutes a propeller selection problem which is solved by the thrust approach. In this approach, the effective horsepower (P_E) and the ship's speed (V) are specified by the designer. From the viewpoint of optimization, the quantities P_E and V become preassigned parameters. This reduces the design vector $\overline{X}$ (see Figure 4.1) to:

$$\overline{X} = \begin{Bmatrix} D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \\ N_P \\ Q_S \end{Bmatrix} \tag{7.1}$$

Having specified P_E and V, all of the design variables, as listed in equation (7.1), are not independent. Recalling equations (3.3) and (3.13), the following relationship results:

$$P_E = \frac{(1-td)}{(1-wt)} \cdot \eta_R \cdot \eta_o \cdot \frac{2\pi Q_S}{550} \cdot \frac{N_P}{60} \qquad (7.2)$$

Rearranging terms, this equation becomes:

$$\eta_o \, Q_S \, N_P = \frac{(1-wt)}{(1-td)} \cdot \frac{P_E}{\eta_R} \cdot \frac{550 \cdot 60}{2\pi} \qquad (7.3)$$

Considering that the open water efficiency (η_o) is evaluated prior to the computation of ($-\eta_o$), or $OBJ_{1,2}$, then both N_P and Q_S are not independent design variables. One must be selected as the independent design variable. Then, the other variable becomes dependent on the one just selected.

For this study, N_P is selected as the independent design variable. This choice will reduce the design vector $\overline{X}$ for propeller selection problems using the thrust approach to the following:

$$\overline{X} = \begin{Bmatrix} D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \\ N_P \end{Bmatrix} \qquad (7.4)$$

Finally, equation (3.8) implies an alternative definition of $\overline{X}$ as given in equation (7.4). The design vector for Design Case No. 1 propeller selection problems is, therefore, defined as:

$$\overline{XI} = \left\{ \begin{array}{l} D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \\ J \end{array} \right\} \tag{7.5}$$

2. Powering Constraint

Having determined the design vector $\overline{XI}$, a final restriction to the general propeller selection problem, as stated by equation (4.24), remains for consideration. This restriction constitutes the remaining constraint $G_{12}(\overline{X})$ mentioned in Chapter IV.

Simply stated, the selected propeller, as defined by $\overline{XI}$, must develop enough thrust (T) so that the powering requirement, specified by P_E and V, is met. Using equation (3.2), the thrust developed by the propeller can be specified in terms of thrust horsepower (P_T) as:

$$(P_T)_{dev} = \frac{T\ V(1-wt)}{550} \tag{7.6}$$

From equation (3.9), it follows that:

$$(P_T)_{dev} = \frac{\rho\ n_P^2\ D^4\ K_T}{550} \cdot V(1-wt) \tag{7.7}$$

Using equation (3.12), the developed thrust horsepower can be defined in terms of developed effective horsepower given by:

$$(P_E)_{dev} = \frac{(1-td)}{(1-wt)} \cdot (P_T)_{dev} \qquad (7.8)$$

The restriction imposed by the thrust approach method, where P_E and V are specified, can now be stated as:

$$P_E \leq (P_E)_{dev} \qquad (7.9)$$

Rearranging equation (7.9), the constraint $G_{12}(\overline{XI})$ follows:

$$G_{12}(\overline{XI}) = 1 - \frac{(P_E)_{dev}}{P_E} \leq 0 \qquad (7.10)$$

With the design vector $\overline{XI}$ and $G_{12}(\overline{XI})$ defined, the propeller selection problem represented by Design Case No. 1 can be stated under one equation as:

$$\begin{aligned} &\text{Maximize:} \quad F(\overline{XI}) = OBJ_{1,2} \\ &\text{Subject to:} \quad G_j(\overline{XI}) \leq 0 \quad j = 1,\ldots,12 \\ &\qquad XI_i^{lower} \leq XI_i \leq XI_i^{upper} \quad i = 1,\ldots,5 \end{aligned} \qquad (7.11)$$

C. PREVIOUS SOLUTIONS

Triantafyllou [Refs. 3,21] considered a propeller selection problem represented by Design Case No. 1. In his example problem, the following parameters were specified:

1) $\nu = 1.139 \times 10^{-6}$ $(m^2/sec) = 1.22613 \times 10^{-5}$ (ft^2/sec)

2) wt = .22

3) td = .19

4) $\eta_R = 1.025$

5) noscrw = 1

6) Z = 5

7) $P_E = 18153$ (hp)

8) V = 24 (knots)

9) D = 22.0 (ft)

10) $A_E/A_O = .85$

The hull under study in his example had the following dimensions:

1) Length = 710 (ft)

2) Draft = 30 (ft)

3) Beam = 100 (ft)

For his analysis, the design vector contained two variables and was specified as:

$$\overline{XT} = \begin{Bmatrix} J \\ P/D \end{Bmatrix}$$

Using an iterative scheme [Ref. 21: p. 79] to solve two equations in two unknowns, he maximized the open water efficiency (η_o) to obtain the following results:

$$P/D = 1.1651$$

$$N_P = 104 \text{ (rpm)}$$

$$P_D = 25544 \text{ (hp)}$$

$$\eta_o = .6676$$

For future comparisons, equations (3.8) and (3.3) give:

$$J = .8286$$

$$Q_S = 1290000.0 \text{ (ft-lbf)}$$

Triantafyllou's results are summarized in Table (IV).

D. SOLUTIONS BY COPES/CONMIN

The propeller selection problem, as stated by equation (7.11), is now solved by COPES/CONMIN. Four solution variations are considered.

The first and second variations attempt to reproduce the solution given by Triantafyllou. The design vector $\overline{XT}$ (NDV = 2) is used in both cases. One variation uses SUBROUTINE STRCNA to evaluate the constraint $G_{12}(\overline{XT})$ given by equation (4.8). The other uses SUBROUTINE STRCNK to determine $G_{12}(\overline{XT})$.

The remaining two variations will solve the propeller selection problem using the design vector $\overline{XI}$ (NDV = 5) defined in equation (7.5). Again, one variation uses SUBROUTINE STRCNA; the other, SUBROUTINE STRCNK.

In all variations, the following parameters are used:

1) Temp = 59 (°F)
2) $\rho = 1.9384$ (lbf-sec^2/ft^4)
3) $\nu = 1.2285$ 10 (ft^2/sec)

4) p_{watvap} = .247 (psia)

5) p_{atm} = 14.7 (psia)

6) wt = .22

7) td = .19

8) η_R = 1.025

9) noscrw = 1

10) h_{c_ℓ} = 19.0 (ft)

11) D_{lim} = 22.0 (ft)

12) Z = 5

13) promat = 5 (stainless steel; see Table (II))

14) P_E = 18153 (hp)

15) V = 24.0 (knots)

All of the above are initialized in the input phase (ICALC = 1) of each SUBROUTINE ANALIZ pertaining to each variation.

The constraint $G_{12}(\overline{XI})$ or $G_{12}(\overline{XT})$ is evaluated by SUBROUTINE BLPOW1 which appears in the execution section of each SUBROUTINE ANALIZ.

1. Variation 1

a. Programming Details

Since this variation uses the design vector $\overline{XT}$, the following design variables of $\overline{XI}$ become parameters and are specified in the input section of SUBROUTINE ANALIZ (ICALC = 1) as:

1) D = 22.0 (ft)

2) A_E/A_O = .85

3) $(t^*/c)_{.75R}$ = .0348 (from equation 3.21).

For constraints, the following are used:

$$G_j(\overline{XT}) \leq 0 \qquad j = 1,\ldots,8,\ 12$$

Only nine of twelve constraints are evaluated (NCON = 9). Obviously, some of the twelve constraints are redundant since D, A_E/A_O, and $(t^*/c)_{.75R}$ have been specified.

The upper (XT_i^{upper}) and lower (XT_i^{lower}) limits on the design variables J and P/D are set to be:

$$.01 \leq J \leq 1.6$$

$$.4 \leq P/D \leq 1.4$$

These upper and lower limits are specified in the COPES control card deck on card image F under respective fields VUB and VLB. The initial value for each design variable (XT_i) is also assigned on card image F under the field labeled X. The first list of card images in Appendix D lists all of the COPES control cards used for this variation and variation 2. These cards also specify the locations of the design variables in the common block GLOBCM (see Table (III)) as well as the locations of the constraints and their boundaries. Further details on the COPES control card requirements and the format of each card are contained in Reference [7].

An examination of SUBROUTINE ANALIZ for this variation, found in Appendix C, shows the calling statement made to SUBROUTINE STRCNA.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed first in Appendix E. Results for this variation of the propeller selection problem are tabulated in Table (IV).

2. Variation 2

a. Programming Details

Everything discussed above for the first variation applies here with one exception. An examination of SUBROUTINE ANALIZ for the second variation, found in Appendix C, shows the calling statement made to SUBROUTINE STRCNK.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed second in Appendix E. Results for this variation of the propeller selection problem are tabulated in Table (IV).

3. Variation 3

a. Programming Details

This variation uses the design vector $\overline{XI}$. For constraints, the following are used:

$$G_j(\overline{XI}) \leq 0 \quad j = 1,\ldots,12$$

All twelve constraints are evaluated (NCON = 12).

The upper (XI_i^{upper}) and lower (XI_i^{lower}) limits on the design variables D, P/D, A_E/A_O, $(t^*/c)_{.75R}$, and J are set as:

$$1.0 \leq D \leq 50.0 \quad \text{(ft)}$$

$$.4 \leq P/D \leq 1.4$$

$$.2 \leq A_E/A_O \leq 1.1$$

$$.003 \leq (t^*/c)_{.75R} \leq .50$$

$$.01 \leq J \leq 1.6$$

These upper and lower limits are specified in the COPES control card deck on card image F under respective fields VUB and VLB. The initial value for each design variable (Xl_i) is also assigned on card image F under the field labeled X. The second list of card images in Appendix D lists all of the COPES control cards used for this variation and variation 4. These cards also specify the locations of the design variables in the common block GLOBCM (see Table (III)) as well as the locations of the constraints and their boundaries. Further details on the COPES control card requirements and the format of each card are contained in Reference [7].

An examination of SUBROUTINE ANALIZ for this variation, found in Appendix C, shows the calling statement made to SUBROUTINE STRCNA.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed third in Appendix E. Results for this variation of thepropeller selection problem are tabulated in Table (IV).

4. Variation 4

a. Programming Details

Everything discussed above for the third variation applies here with one exception. An examination of SUBROUTINE ANALIZ for the fourth variation, found in Appendix C, shows the calling statement made to SUBROUTINE STRCNK instead of SUBROUTINE STRCNA.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed last in Appendix E. Results for this variation of the propeller selection problem are tabulated in Table (IV).

E. DISCUSSION

Overall, the results achieved in all variations compare reasonably well to the solution obtained by Triantafyllou. However, the following points can be made.

Variations 1 and 2 give the same results. This was expected in view of the fact that, even though constraints $G_9(\overline{XT})$ through $G_{11}(\overline{XT})$ were evaluated, these constraints were not considered in the optimization search conducted by CONMIN.

In variations 3 and 4, the diameter (D) was driven to the limit (D_{lim}). This bears out a fundamental rule in propeller design, i.e., the larger the propeller diameter (D), the greater the open water efficiency (η_o).

The minimum required equivalent blade section maximum thickness-to-chord ratio ($(t^*/c)_{.75R\,min}$), computed in

variation 3, is substantially smaller than the one computed for variation 4. As pointed out in Reference [2], the empirical relation, expressed by equation (4.9) and derived from equation (70.x) [Ref. 46: p. 620], does not take into account the effects of centrifugal loading. These effects include, specifically, the direct stresses imposed by the inertia load of the blade and the bending moments which result from rake and skew of the blade. Therefore, the algorithm developed in Chapter VI should, and does, produce a larger value for $(t^*/c)_{.75R}$.

A final observation on the results concerns the values of the open water efficiency. The "optimum" open water efficiency (η_o) achieved by Triantafyllou is lower than those achieved in variations 1 and 2. A possible reason for this might be the neglection of the term "dRe/dJ" in Triantafyllou's formulation of the analytical expressions [Ref. 21: p. 71] that he used in his analysis. The difference in the open water efficiencies subsequently accounts for the differences in the propeller revolution rate (N_p) and the delivered torque (Q_S) when the relation in equation (3.3) is considered.

TABLE IV

Design Case No. 1--Results

GROUP	ITEM	TRIANTA-FYLLOU	1	2	3	4
	P_E	18153.0	18153.0	18153.0	18153.0	18153.0
Given	V	24.0	24.0	24.0	24.0	24.0
Design Variable Specified	D	22.0	22.0	22.0		
	A_E/A_O	.85	.85	.85		
	$(t^*/c)_{.75R}$		.0348	.0348		
	D				21.9991	21.9659
Design Variables	P/D	1.1651	1.0036	1.0036	.9981	1.0071
	A_E/A_O				.8205	.8149
	$(t^*/c)_{.75R}$				.0330	.0642
	J	.8286	.7371	.7371	.7343	.7394
Maximize	η_o	.6676	.7091	.7091	.7109	.7066
	D_{lim}		(22.0)	(22.0)	22.0	22.0
Restrictions	$A_E/A_{O\,min}$		(0.5258)	(0.5258)	.5269	.5267
	$(t^*/c)_{.75Rmin}$		(0.21266)	(0.50761)	.021998	.053259
	N_P	104	116.9	116.9	117.4	116.7
Other	Q_S	1290000	1080451.	1080451	1064574	1084003
	P_D	25544.0	24051.3	24051.3	24030.3	24094.8

VIII. DESIGN CASE NO. 2--PROGRAMMING AND COMPARISONS

A. INTRODUCTION

In this chapter, COPES/CONMIN is used in the solution of propeller selection problems which use the "power" approach. First, the power approach to the propeller selection problem is formulated. Then, a review of a previous author's solution to this problem is presented. Four variations to this propeller selection problem are solved by COPES/CONMIN. The chapter is completed with a presentation and discussion of the results from the four variations.

B. POWER APPROACH FORMULATION

1. Design Vector $\overline{X2}$

As previously pointed out at the conclusion of Chapter III, Design Case No. 2 constitutes a propeller selection problem which is solved by the power approach. In this approach, the delivered torque (Q_S) and the propeller revolution rate (N_p) are specified by the designer. From the viewpoint of optimization, the quantities Q_S and N_p become preassigned parameters. This reduces the design vector $\overline{X}$ (see Figure (4.1)) to:

$$\overline{X} = \begin{Bmatrix} P_E \\ V \\ D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \end{Bmatrix} \tag{8.1}$$

Having specified Q_S and N_P, all of the design variables, as listed in equation (8.1), are not independent. Recalling equations (3.3), (3.11) and (3.13), the following relationship results:

$$P_E = \frac{(1-td)}{(1-wt)} \cdot \eta_R \cdot \frac{J\ K_T}{2\pi K_Q} \cdot \frac{2\pi Q_S}{550} \cdot \frac{N_P}{60} \qquad (8.2)$$

Rearranging terms, this equation becomes:

$$\frac{P_E}{V} = \frac{(1-td)}{(1-wt)} \cdot \eta_R \cdot \frac{(1-wt)}{n_P\ D} \cdot \frac{K_T}{K_Q} \cdot \frac{Q_S}{550} \cdot \frac{N_P}{60} \qquad (8.3)$$

Considering the relations for K_T and K_Q in equation (3.17), then both P_E and V are not independent design variables. One must be selected as independent, while the other becomes dependent on the one selected.

For this study, V is selected as the independent design variable. This choice will reduce the design vector $\overline{X}$ for propeller selection problems using the power approach to the following:

$$\overline{X} = \begin{Bmatrix} V \\ D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \end{Bmatrix} \qquad (8.4)$$

Finally, equation (3.8) implies an alternative definition of $\overline{X}$ as given in equation (8.4). The design vector for

Design Case No. 2 propeller selection problems is, therefore, defined as:

$$\overline{X2} = \left\{ \begin{array}{l} V \\ J \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \end{array} \right\} \qquad (8.5)$$

2. Powering Constraint

Having determined the design vector $\overline{X2}$, a final restriction to the general propeller selection problem, as stated by equation (4.24), remains for consideration. This restriction constitutes the remaining constraint $G_{12}(\overline{X})$ mentioned in Chapter IV.

Simply stated, the selected propeller, as defined by X2, must absorb at least all of the power delivered to it (P_D) which is specified in terms of Q_S and N_P. Using equation (3.3), the power absorbed by the propeller can be specified in terms of delivered horsepower (P_D) as:

$$(P_D)_{absorb} = \frac{2\pi\ Q_P}{550} \cdot \frac{N_P}{60} \qquad (8.6)$$

From equation (3.10), it follows that:

$$(P_D)_{absorb} = \frac{K_Q\ \rho\ n_P^2\ D^5}{550} \cdot \frac{2\pi\ N_P}{60} \qquad (8.7)$$

But, equation (3.3) also defines the power delivered to the propeller as:

$$P_D = \frac{2\pi\ Q_S}{550} \cdot \frac{N_P}{60} \qquad (8.8)$$

The restriction imposed by the power approach method, where Q_S and N_P are specified, can now be stated as:

$$P_D \leq (P_D)_{absorb} \qquad (8.9)$$

Rearranging equation (8.9), the constraint $G_{12}(\overline{X2})$ follows:

$$G_{12}(\overline{X2}) = 1 - \frac{(P_D)_{absorb}}{P_D} \leq 0 \qquad (8.10)$$

Further simplification of equation (8.10) gives:

$$G_{12}(\overline{X2}) = 1 - \frac{Q_P}{Q_S} \leq 0 \qquad (8.11)$$

With the design vector $\overline{X2}$ and $G_{12}(\overline{X2})$ defined, the propeller selection problem represented by Design Case No. 2 can be stated under one equation as:

$$\begin{aligned} &\text{Minimize:} \quad F(\overline{X2}) = OBJ_{1,2} \\ &\text{Subject to:} \quad G_j(\overline{X2}) \leq 0 \quad j = 1,\ldots,12 \\ &\qquad X2_i^{lower} \leq X2_i \leq X2_i^{upper} \quad i = 1,\ldots,5 \end{aligned} \qquad (8.12)$$

C. PREVIOUS SOLUTIONS

Markussen [Ref. 4] considered a propeller selection problem represented by Design Case No. 2. In his example problem,

the following parameters were specified:

1) Temp = 18 (°C) = 64.4 (°F)
2) P_{watvap} = 0.0206411 (bars) = .29943921 (psia)
3) P_{atm} = 1.01312856 (bars) = 14.6974 (psia)
4) noscrw = 1
5) $h_{c\ell}$ = 6.7 (meters) = 21.9827 (ft)
6) Z = 6
7) P_D = 18.9 (MegaWatts) = 25344.9 (hp)
8) N_P = 110 (rpm)
9) V_A = 15.65 (knots)

For his analysis, the design vector contained three variables and was specified as:

$$\overline{XM} = \begin{Bmatrix} J \\ P/D \\ A_E/A_O \end{Bmatrix}$$

A restriction for the minimum required expanded area ratio ($(A_E/A_O)_{min}$), given by equation (4.3), was also considered. This imposed a constraint given by equation (4.4).

Using an iterative scheme [Ref. 4: p. 110] to solve three equations in three unknowns, Markussen maximized the open water efficiency (η_o) to obtain the following results:

$$J = .61095$$

$$P/D = .864380$$

$$A_E/A_O = 36.1861/40.6123 \ (m^2/m^2)$$

$$= .891012$$

$$\eta_o = .654391$$

For future comparisons, equations (3.8) and (3.3) give:

$$D = 7.19091 \text{ (meters)} = 23.593375 \text{ (ft)}$$

$$Q_S = 1210130.0 \text{ (ft-lbf)}$$

Markussen's results are summarized in Table (V).

D. SOLUTIONS BY COPES/CONMIN

The propeller selection problem, as stated by equation (8.12), is now solved by COPES/CONMIN. Four solution variations are considered.

The first and second variations attempt to reproduce the solution given by Markussen. The design vector $\overline{XM}$ (NDV = 3) is used in both cases. One variation uses SUBROUTINE STRCNA to evaluate the constraint $G_{12}(\overline{XM})$ given by equation (4.8). The other uses SUBROUTINE STRCNK to determine $G_{12}(\overline{XM})$.

The remaining two variations will solve the propeller selection problem using the design vector $\overline{X2}$ (NDV = 5) defined in equation (8.5). Again, one variation uses SUBROUTINE STRCNA; the other, SUBROUTINE STRCNK.

In all variations, the following parameters are used:

1) Temp = 64.4 (°F)
2) $\rho = 1.9892$ (lbf-sec^2/ft^4)
3) $\nu = 1.1900 \times 10^{-5}$ (ft^2/sec)
4) $p_{watvap} = .2994$ (psia)

5) p_{atm} = 14.697 (psia)

6) wt = .22

7) td = .19

8) η_R = 1.025

9) noscrw = 1

10) $h_{c\ell}$ = 21.9827 (ft)

11) D_{lim} = 30.0 (ft)

12) Z = 6

13) promat = 5 (stainless steel; see Table (II))

14) Q_S = 1210130 (ft-lbf)

15) N_p = 110 (rpm)

All of the above are initialized in the input phase (ICALC = 1) of each SUBROUTINE ANALIZ pertaining to each variation.

The constraint $G_{12}(\overline{X2})$ or $G_{12}(\overline{XM})$ is evaluated by SUBROUTINE BLPOW2 which appears in the execution section of each SUBROUTINE ANALIZ.

1. Variation 1

a. Programming Details

Since this variation uses the design vector $\overline{XM}$, the following design variables of $\overline{X2}$ become parameters and are specified in the input section of SUBROUTINE ANALIZ (ICALC = 1). The ship's speed (V) is specified as:

$$V = V_A/(1-wt)$$

$$= 15.65/(1 - .22)$$

$$= 20.0641 \text{ (knots)}$$

Markussen elected to use the standard Wageningen blade section maximum thickness-to-chord ratios. Since the equivalent t/c is given as a function of Z and A_E/A_O (see equation (3.21)), then $(t^*/c)_{.75R}$ is calculated during each analysis (ICALC = 2) by the following relation:

$$(t^*/c)_{.75R} = (t/c)_{.75R}$$

For constraints, the following are used:

$$G_j(\overline{XT}) \leq 0 \qquad j = 1,\ldots,8,\ 10,\ 12$$

Only ten of twelve constraints are considered (NCON = 10). Constraints $G_9(\overline{XM})$ and $G_{11}(\overline{XM})$ are redundant since no limit on the propeller diameter (D_{lim}) appears as a parameter in Markussen's formulation and $(t^*/c)_{.75R}$ was taken to be the Wageningen standard.

The upper (XM_i^{upper}) and lower (XM_i^{lower}) limits on the design variables J, P/D and A_E/A_O are set to be:

$$.01 \leq J \leq 1.1$$

$$.4 \leq P/D \leq 1.4$$

$$.4 \leq A_E/A_O \leq 1.1$$

These upper and lower limits are specified in the COPES control card deck on card image F under respective fields VUB and VIB. The initial value for each design variable (XM_i) is

also assigned on card image F under the field labeled X. The first list of card images in Appendix G lists all of the COPES control cards used for this variation and variation 2. These cards also specify the locations of the design variables in the common block GLOBCM (see Table (III)) as well as the locations of the constraints and their boundaries. Further details on the COPES control card requirements and the format of each card are contained in Reference [7].

An examination of SUBROUTINE ANALIZ for this variation, found in Appendix F, shows the calling statement made to SUBROUTINE STRCNA.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed first in Appendix H. Results for this variation of the propeller selection problem are tabulated in Table (V).

2. Variation 2

a. Programming Details

Everything discussed above for the first variation applies here with one exception. An examination of SUBROUTINE ANALIZ for the second variation, found in Appendix F, shows the calling statement made to SUBROUTINE STRCNK instead of SUBROUTINE STRCNA.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed second in Appendix H.

Results for this variation of the propeller selection problem are tabulated in Table (V).

3. Variation 3

a. Programming Details

This variation uses the design vector $\overline{X2}$. For constraints, the following are used:

$$G_j(\overline{X2}) \leq 0 \qquad j = 1,\ldots,12$$

All twelve constraints are evaluated (NCON = 12).

The upper ($X2_i^{upper}$) and lower ($X2_i^{lower}$) limits on the design variables V, P/D, A_E/A_O, $(t^*/c)_{.75R}$, and J are set as:

$$10.0 \leq V \leq 100.0 \quad \text{(ft/sec)}$$

$$.4 \leq P/D \leq 1.4$$

$$.4 \leq A_E/A_O \leq 1.1$$

$$.003 \leq (t^*/c)_{.75R} \leq .50$$

$$.01 \leq J \leq 1.1$$

These upper and lower limits are specified in the COPES control card deck on card image F under respective fields VUB and VLB. The initial value for each design variable ($X2_i$) is also assigned on card image F under the field labeled X. The second list of card images in Appendix G lists all of the COPES control cards used for this variation and variation 4. These cards also specify the locations of the design variables

in the common block GLOBCM (see Table (III)) as well as the locations of the constraints and their boundaries. Further details on the COPES control card requirements and the format of each card are contained in Reference [7].

An examination of SUBROUTINE ANALIZ for this variation, found in Appendix F, shows the calling statement made to SUBROUTINE STRCNA.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed third in Appendix H. Results for this variation of the propeller selection problem are tabulated in Table (V).

4. Variation 4

a. *Programming Details*

Everything discussed above for the third variation applies here with one exception. An examination of SUBROUTINE ANALIZ for the fourth variation, found in Appendix F, shows the calling statement made to SUBROUTINE STRCNK instead of SUBROUTINE STRCNA.

b. Results

The output from the optimization/analysis, performed by COPES/CONMIN, is listed last in Appendix H. Results for this variation of the propeller selection problem are tabulated in Table (V).

E. DISCUSSION

The results achieved in variations 1 and 2 compare extremely well to the solution obtained by Markussen. As

pointed out in the discussion in Chapter VII, variations 1 and 2 are expected to give the same results for the vector $\overline{XM}$. Obviously, the values obtained for J and P/D, as well as those for D, and $Rn^*_{.75R}$, are very close to the values generated in Markussen's example. However, the values for A_E/A_O are somewhat different. It is interesting to note that the value obtained in variations 1 and 2 (and, for that matter, variations 3 and 4) is, essentially, the limiting value for A_E/A_O, as given in Table (I), for Z = 6. Markussen's value for A_E/A_O (i.e., .891012) exceeds the limit (i.e., .80) in this table.

As pointed out at the end of Chapter VII, the minimum required blade section maximum thickness-to-chord ratio $((t^*/c)_{.75R\,min})$, computed in variations 1 and 3, is substantially smaller than the one computed for variations 2 and 4. Again, the same explanation applies here as well.

The results of variations 3 and 4 differ somewhat from Markussen's results. The reason for this is simply that V_A (or V) has not been specified as a parameter. Consequently, a higher value for the advance ratio (J), which corresponds to a higher open water efficiency (η_o), has been found in the optimization search. This result can be interpreted in the following way. Given:

1) a six-bladed Wageningen propeller (Z = 6) which is made out of stainless steel (promat = 5);

2) a power train delivering 25344.9 (hp) at a rate of 110 (rpm);

3) a hull with a wake fraction (wt) equal to .22, a thrust deduction (td) equal to .19 and a shaft centerline depth ($h_{c\ell}$) of 21.98 (ft),

then, the selected propeller, as defined by $\overline{X2}$, can drive this hull at a maximum speed of V when the hull has a maximum resistance given by P_E.

TABLE V

Design Case No. 2--Results

GROUP	ITEM	MARKUSSEN	VARIATIONS			
			1	2	3	4
	P_D	25344.9	25344.9	25344.9	25344.9	25344.9
Given	Q_S	1210130	1210130	1210130	1210130	1210130
	N_P	110	110	110	110	110
Design Variable Specified	V_A	15.65	15.65	15.65		
	V		20.0641	20.0641		
	J	.61095	.6475	.6475	.9927	.8753
	V				30.9138	29.5355
Design Variables	V_A				24.1127	23.0377
	P/D	.864380	.9036	.9036	1.1986	1.0308
	A_E/A_O	.891012	.8018	.8018	.7946	.7986
	$(t^*/c)_{.75R}$		.0397	.0397	.0499	.0638
Maximize	η_o	.654391	.6660	.6660	.7643	.7330
	D_{lim}		(30.0)	(30.0)	30.0	30.0
Restrictions	$A_E/A_{O\,min}$	.574729	.5070	.5070	.4622	.4266
	$(t^*/c)_{.75R\,min}$		(.02729)	(.0647)	.02706	.0638
	D	23.53	22.25	22.25	22.36	24.23
Other	P_E		(14057.3)	(14057.3)	19945.5	20653.7
	$Rn^*_{.75R}$	6.478×10^7	5×10^7	5×10^7	5×10^7	5×10^7

IX. DESIGN CASE NO. 3--PROGRAMMING AND COMPARISONS

A. INTRODUCTION

In this chapter, COPES/CONMIN is used in the solution of a propeller selection problem where "matching" is desired. First, the "matching" approach to the propeller selection problem is formulated. Then, a review of a previous author's solution is presented. One variation to this propeller selection problem is solved by COPES/CONMIN. The chapter is completed with a presentation and discussion of the results.

B. "MATCHING" FORMULATION

1. Design Vector $\overline{X3}$

Design Case No. 3, the final powering problem considered in this study, constitutes a propeller selection problem solved by the "matching" approach. In this approach, the hull's effective horsepower (P_E) and speed (V), the delivered torque (Q_S) and the propeller revolution rate (N_P) are specified by the designer. This reduces the design vector $\overline{X}$ (see Figure (4.1)) to:

$$\overline{X} = \begin{Bmatrix} D \\ P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \end{Bmatrix} \tag{9.1}$$

For this study, the design vector $\overline{X}$ is reduced further by eliminating the propeller diameter (D) as a design variable.

That is, D will also be specified by the designer so that the design vector for Design Case No. 3 is defined as:

$$\overline{X3} = \begin{Bmatrix} P/D \\ A_E/A_O \\ (t^*/c)_{.75R} \end{Bmatrix} \tag{9.2}$$

2. Powering Constraint(s)

Having determined the design vector $\overline{X3}$, a final restriction to the general propeller selection problem, as stated by equation (4.24), remains for consideration. This restriction constitutes the remaining constraint $G_{12}(\overline{X})$ mentioned in Chapter IV as well as an additional constraint.

In the "matching" problem, the selected propeller, as defined by $\overline{X3}$, must satisfy two conditions. First, it must develop, as a minimum, the effective horsepower (P_E) as imposed by the design specification. Citing the formulation previously derived in Chapter VII, this condition can be stated as:

$$P_E \geq (P_E)_{dev} \tag{9.3}$$

The constraint $G_{12}(\overline{X3})$ follows accordingly as:

$$G_{12}(\overline{X3}) = 1 - \frac{(P_E)_{dev}}{P_E} \leq 0 \tag{9.4}$$

For the second condition, the selected propeller can only absorb, as a maximum, the delivered power (P_D) as

specified by the designer. The formulation is the same as that in Chapter VIII except that the inequality signs are reversed. The condition is stated as:

$$(P_D)_{absorb} \leq P_D \tag{9.5}$$

In defining a constraint $G_{13}(\overline{X3})$, another location, say location 24, in the GLOBCM block (see Table (III)) would be assigned. But, considering the fact that constraint $G_9(\overline{X})$ will not be used because the propeller diameter (D) is specified, there is no reason why $G_9(\overline{X3})$ cannot be redefined, for this Design Case only, as:

$$G_9(\overline{X3}) = \frac{(P_D)_{absorb}}{P_D} - 1 \leq 0 \tag{9.6}$$

Further simplification of equation (9.6) gives:

$$G_9(\overline{X3}) = \frac{Q_P}{Q_S} - 1 \leq 0 \tag{9.7}$$

In reality, the constraints just defined should be equality constraints. The word "match" does infer equality in some sense. However, as previously stated in Chapter II, the version of COPES/CONMIN used in this study does not directly handle equality constraints. But, since CONMIN attempts to minimize constraints in the optimization search, it will be assumed that a "match" can be achieved.

With the design vector $\overline{X3}$ and the constraints $G_{12}(\overline{X3})$ and $G_9(\overline{X3})$ defined, the propeller selection problem represented by Design Case No. 3 can now be stated under one equation as:

$$\begin{aligned} &\text{Minimize:} \quad F(\overline{X3}) = OBJ_3 \\ &\text{Subject to:} \quad G_j(\overline{X3}) \leq 0 \qquad j = 1,\ldots,12 \qquad (9.8) \\ &\qquad X3_i^{lower} \leq X_i \leq X3_i^{upper} \qquad i = 1,\ldots,3 \end{aligned}$$

C. PREVIOUS SOLUTIONS

The propeller selection problem considered by Vassilopoulos [Ref. 18] actually represents a propeller "design" problem using the "power" approach. The example problem which he elected to solve is taken from that posed by the International Towing Tank Conference (ITTC) Propeller Committee. This problem is concerned with the determination of propeller thrust (T), diameter (D) and speed of advance (V_A) (or ship speed (V)) for a single-screw cargo ship where:

1) power available to the propeller (i.e., P_D) is 30,000 (hp)
2) Z = 6
3) N = 105--110 (rpm)
4) D_{lim} = 23 (ft)
5) $h_{c\ell}$ = 19 (ft)

The variation of ship speed (V) and of hull effective power (P_E), thrust deduction factor (td) and the wake fraction (wt) is also given [Ref. 18: p. 20].

The results from Vassilopoulos' propeller design exercise produced a propeller that is "matched" at the following values:

1) P_E = 21292.6 (hp)
2) V = 24.24 (knots)
3) Q_S = 1500606.75 (ft-lbf)
4) N_P = 105 (rpm)
5) P_D = 30000.0 (hp)

His propeller "design" was based upon the following specified parameters:

1) Temp = 59 (°F)
2) ρ = 1.9905 ($lbf\text{-}sec^2/ft^4$)
3) p_{watvap} = .247 (psia)
4) wt = .22
5) td = .1725
6) noscrw = 1
7) $h_{c\ell}$ = 19.0 (ft)
8) Z = 6
9) promat = 5 (stainless teel, see Table (II))
10) D = 22.0 (ft)
11) N_P = 105 (rpm)
12) P_D = 30000.0 (hp)

Using an optimization scheme incorporated in his MVAPDP computer program, Vassilopoulos maximized the open water efficiency (η_o) and designed a propeller with the following characteristics:

1) J = .852
2) K_T = .242

3) $K_Q = .0478$

4) $\eta_o = .691$

5) $A_E/A_O = .767$

6) bldwt = 7617.2 (lbf)

By utilizing both the lifting line and lifting surface methods in his design procedure, Vassilopoulos' MVAPDP program evolved a "constant stress" propeller blade. Consequently, the values for (t*/c) and P/D varied non-linearly along the propeller radius (R). According to Vassilopoulos, this resulted in a minimum weight propeller. The values for P/D and (t*/c) are listed in Tables (8) and (10) of his paper. From these values, $(t^*/c)_{.75R}$ is approximately .040.

While the propeller represented by Vassilopoulos' design is different, in many aspects (rake, skew, blade section aerfoil shape, etc.), from the Wageningen B-Screw Series propeller, it does represent a minimum weight propeller that has been "matched" to specific design values. Appropriate results are summarized in Table (VI).

D. SOLUTIONS BY COPES/CONMIN

The propeller selection problem, as stated by equation (9.8), is now solved by COPES/CONMIN. One solution variation is considered. The following parameters are used:

1) Temp = 59 (°F)

2) $\rho = 1.9905$ (lbf-sec^2/ft^4)

3) $\nu = 1.2817 \times 10^{-5}$ (ft^2/sec)

4) $p_{watvap} = .247$ (psia)

5) p_{atm} = 14.7 (psia)

6) wt = .22

7) η_R = 1.025

8) noscrw = 1

9) $h_{c\ell}$ = 19.0 (ft)

10) Z = 6

11) promat = 5 (stainless steel, see Table (II))

12) D = 22.0 (ft)

Two problems are examined. Problem 1 specifies the following additional parameters:

1) td = .1725

2) P_E = 21292.6 (hp)

3) V = 24.24 (knots)

4) Q_S = 1500606.75 (ft-lbf)

5) N_P = 105 (rpm)

Problem 2 specifies the same parameters as:

1) td = .171

2) P_E = 17630.0 (hp)

3) V = 23.0 (knots)

4) Q_S = 1500606.75 (ft-lbf)

5) N_P = 105 (rpm)

All of the above are initialized in the input section (ICALC = 1) of similar versions of SUBROUTINE ANALIZ. Therefore, only one version is included in Appendix I.

The constraints for $G_9(\overline{X3})$ and $G_{12}(\overline{X3})$ are evaluated by SUBROUTINE BLPOW3 which appears in the execution section of

SUBROUTINE ANALIZ. Also, note that SUBROUTINE DICNUA has been deleted from the execution section, while SUBROUTINE WGTCAL has been added.

1. Programming Details

All twelve constraints are evaluated (NCON = 12). The upper ($X3_i^{upper}$) and lower ($X3_i^{lower}$) limits on the design variables P/D, A_E/A_O and $(t^*/c)_{.75R}$ are set to be:

$$.4 \leq \quad P/D \quad \leq 1.4$$

$$.4 \leq \quad A_E/A_O \quad \leq 1.1$$

$$.003 \leq \quad (t^*/c)_{.75R} \quad \leq .50$$

These upper and lower limits are specified in the COPES control card deck on card image F under respective fields VUB and VLB. The initial value for each design variable ($X3_i$) is also assigned on card image F under the field labeled X. The list of card images in Appendix J lists all of the COPES control cards used for both problems. These cards also specify the locations of the design variables in the common block GLOBCM (see Table (III)) as well as the locations of the constraints and their boundaries. Further details on the COPES control card requirements and the format of each card are contained in Reference [7].

2. Results

The outputs from the optimization/analysis, performed by COPES/CONMIN, are listed in Appendix K. Results of both problems are tabulated in Table (VI).

E. DISCUSSION

Table (VI) presents the results of problems 1 and 2 along with relevant information from Vassilopoulos' "design". Problem 1 attempted to "match" a Wageningen propeller at the design point found by Vassilopoulos. The first COPES/CONMIN printout in Appendix K indicates that the "match" was achieved at P_E equal to 21.168.1 (hp) and P_D equal to 28,150.0 (hp) (or, Q_S = 1500607 (ft-lbf) and N_P = 105 (rpm)). These values are judged to be close enough to the "Given" values in Table (VI).

It is apparent that the Wageningen propeller does not require all of the 30,000 (hp) of delivered horsepower. The propeller characteristics (i.e., J, K_T, K_Q and η_o) for problem 1 compare very well to Vassilopoulos' values. The expanded area ratios (A_E/A_O) are, also, very similar. Of course, the obvious difference is the blade weight (bldwt). The Wageningen propeller blade is over five thousand pounds heavier. Does this make sense for a minimum blade weight?

The answer is yes.

All one has to do is consider the values of (t*/c) for problem 1 and Vassilopoulos' design. Vassilopoulos' "constant stress" blade was designed to "absorb" stress up to the allowable design limit of 5,400 (psi) (for stainless steel) <u>all along</u> the entire propeller radius (R). Table (12) in Reference [18] gives further details. The Wageningen propeller blade, however, represents an "older" type of blade which was designed with a <u>linear</u> blade section maximum thickness (t*)

distribution. Consequently, it was "overdesigned" for strength beyond the 3/10--4/10 radius (i.e., .3R--.4R) and contains excess material. A heavier blade, therefore, results. Note, also, that the optimizer did not drive the value of $(t^*/c)_{.75R}$ to the minimum acceptable value, $(t^*/c)_{.75R\,min}$.

The results of problem 2 show the effect on blade weight (bldwt) for a Wageningen propeller when the hull's powering requirements (i.e., P_E at V) have been reduced. The weight reduction of 2000 pounds is significant. The complete results are listed in the second COPES/CONMIN printout in Appendix K.

TABLE VI

Design Case No. 3--Results

GROUP	ITEM	VASSILOPOULOS	PROBLEM	
			1	2
Given	P_E	21292.6	21292.6	17630.0
	V	24.24	24.24	23.0
	Q_S	1500607	1500607	1500607
	N_P	105	105	105
Design Variable Specified	D	22.0	22.0	22.0
Design Variables	P/D	*	1.1813	1.0906
	A_E/A_O	.767	.7944	.7742
	$(t^*/c)_{.75R}$	.040	.0794	.0681
Minimize	bldwt	—	12842.6	10464.7
Maximize	η_o	.691	—	—
Restrictions	D_{lim}	—	—	—
	$A_E/A_{O\,min}$	—	.8515	.7722
	$(t^*/c)_{.75R\,min}$	—	.0691	.0681
Other	J	.852	.8290	.7866
	K_T	.242	.2349	.2063
	K_Q	.0478	.0448	.0372
	η_o	—	.6915	.6950
	bldwt	7617.2	—	—

*P/D varies with R

X. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The general purpose non-linear optimizer/synthesizer COPES/CONMIN has been successfully applied to three typical preliminary ship design propeller selection problems in which the Wageningen B-Screw Series is used. The formulation and programming of each required analysis code (i.e., SUBROUTINE ANALIZ) have been made as general as possible to allow the designer a broad variety of solution options for solving propeller selection problems which can be classified under any of the three Design Cases that were considered. The analysis codes have been "modularized" to the extent that methodical series data from other propeller series, which are available in the polynomial expression format of the B-Screw Series, can be easily adapted for powering analysis utilizing design optimization methods.

Further flexibility in the solution to the propeller selection problem has been achieved by using COPES/CONMIN as the optimizer/synthesizer. The designer has now been afforded the additional capability of specifying the design variables, the objective functions and the constraints of his choice. By solving propeller selection problems in the way presented in this thesis, repetitive problem formulation and coding have been eliminated.

There are other advantages to solving propeller selection problems specifically with COPES/CONMIN which have not been

directly addressed in this study. As stated in Chapter II, COPES/CONMIN is capable of performing optimization analyses, sensitivity studies, optimum sensitivity studies and optimization using approximation techniques. The designer, therefore, can select and perform any of these options, using the same analysis codes which have been presented in this thesis.

While the utilization of a general purpose non-linear optimizer in solving propeller selection problems allows the designer greater flexibility in the selection procedure, there is one important limitation that should be stressed at this point. This concerns the question whether or not the solution vector, determined by the optimizer, is a "global" optimum. As stated in Chapter II, COPES/CONMIN assures that, if a feasible solution vector is found, it is, at least, a "local" minimum (or maximum). This implies that, for two different initial design vectors which are specified in the COPES Control Card deck on card image F, the same optimum solution may not be determined by the optimizer. Both solutions would correspond to minimums (or maximums) of the objective function and are, therefore, correct. But, does one or the other correspond to the minimum (or maximum) of the entire vector design space, i.e., the "global" optimum? For the moment, at least, there is no definitive answer to the question.

Despite this uncertainty, progress in the field of design optimization continues to be made. Current developments [Ref. 47] will soon allow the designer to have a choice in

selecting a specific optimization algorithm from a "library" of proven optimization programs which employ the latest state-of-theart numerical techniques. Again, using one analysis code, the designer will be able to generate any number of optimized solutions for the problem under study.

B. RECOMMENDATIONS

For future consideration, it is recommended that the automated design and trade-off capability, provided by a general purpose non-linear optimizer/synthesizer such as COPES/CONMIN, be applied to the more difficult problem of propeller design.

As pointed out in Chapter I, the use of the Wageningen B-Screw Series represents a "selection" procedure rather than a "design" process. Today, analytical propeller design procedures, utilizing lifting line and lifting surface theory, are becoming increasingly popular among propeller designers. The propeller design, which results from the utilization of these analytical methods, is, unquestionably, more efficient than the standard series propeller. However, these methods require consideration of many more design variables in the design process. This appears to be a natural application for the use of a general purpose non-linear optimizer/synthesizer.

Here, an analysis code, much larger than those which have been presented in this study, could be developed which would incorporate the lifting line/lifting surface theory

for the determination of the propeller performance characteristics, the local cavitation numbers and also the calculation of the pressure distributions over the blade. These pressure distributions would be utilized in the strength analysis of the blade. This analysis would utilize the finite element technique on an appropriately generated mesh model of the blade. Having defined the steps for this design procedure in the analysis code, the propeller designer now "couples" his analysis to the optimizer/synthesizer for determination of the optimum design. A massive amount of computer storage would certainly be required, but this concept is feasible and, in the author's view, is worthy of future consideration.

C. A FINAL NOTE

In conclusion, this thesis has demonstrated, in effect, another interesting application of the method of design optimization. The author, in no way, wishes to leave the reader with the impression that the techniques of design optimization are the "be all--end all" for engineering analysis. Design optimization techniques are useful and powerful tools that stand to relieve the engineer of the mundane tasks of numerical calculations and subsequent graphic plotting. But, they are just tools. In the final "analysis", good engineering judgment is paramount in their application and use.

APPENDIX A

FORTRAN VARIABLE CROSS REFERENCE LIST

Symbol	Fortran Variable
A_E/A_O	AEDVAO
$(A_E/A_O)_{min}$	AEAOMN
bldwt	WEIGHT
$c_{.75R}$	C75R
D	DIA
D_{lim}	DIALIM
$h_{c\ell}$	HCL
J	RJ
K_Q	KQ
K_T	KT
noscrw	NOSCRW
N_P	N
P_E	PE
P_D	PD
P/D	PDIVD
p_{watvap}	PWATVA
p_{atm}	PATM
promat	PROMAT
Q_S	QS
$Rn^*_{.75R}$	R75R
S_c	SC
td	TD

APPENDIX A (CONT.)

Symbol	Fortran Variable
Temp	TEMP
$(t^*/c)_{.75R}$	TC75R
V (ft/sec)	V
V (knots)	VK
wt	WT
Z	Z
η_o	ETAO
η_R	ETARR
ν	WATNU
ρ	WATRO

```
      SUBROUTINE ELDPRP                                                 APP0C010
C                                                                       APP00020
C                                                                       APP0C030
C     SUBROUTINE:  BLDPRP                 DATE OF LAST REVISION: APR 83 APP00040
C                                                                       APP00050
C     INPUT              OUTPUT           DEFINITION                    APP0C060
C                                                                       APP0C070
C     AEOVAO                              EXPANDED AREA RATIO           APP00080
C     DIA                                 PROPELLER DIAMETER (FEET)     APP0C090
C     Z                                   NO. OF PROPELLER BLADES       APP00100
C     COMMON /THICO/                      BLADE SECTION MAXIMUM         APP00110
C                                         THICKNESSESS ALONG PROPELLER  APP00120
C                                         RADIUS (FEET)                 APP00130
C                        COMMON/AREBLD/   BLADE SECTION AREAS (FEET**2)  APP0C140
C                        COMMON/CGX/      LOCATION OF BLADE CROSS-SEC-  APP00150
C                                         TIONAL AREA CENTROID WITH     APP0C160
C                                         RESPECT TO GENERATOR LINE     APP0C170
C                                         (FEET)                        APP00180
C                        COMMON/CGY/      LOCATION OF BLADE CROSS-SEC-  APP0C190
C                                         TIONAL AREA CENTROID WITH     APP00200
C                                         RESPECT TO PITCH-REFERENCE    APP0C210
C                                         LINE (FEET)                   APP0C220
C                        COMMON/CRDLNT/   BLADE SECTION CHORD LENGTHS   APP0C230
C                                         (FEET)                        APP0C240
C                        COMMON/VALU1/    ORDINATE OF CRITICAL POINT NO.APP0C250
C                                         1 ON BLADE SECTION PERIPHERY  APP00260
C                                         WITH RESPECT TO A SYSTEM OF   APP0C270
C                                         AXES PARALLEL AND NORMAL TO   APP0C280
C                                         PITCH-REFERENCE LINE WITH ORI-APP0C290
C                                         GIN AT THE CENTROID OF THE    APP0C300
C                                         SECTION (FEET)                APP00310
C                        COMMON/VALW1/    ABCISSA OF CRITICAL POINT NO. APP0C320
C                                         1 ON BLADE SECTION PERIPHERY  APP0C330
C                                         WITH RESPECT TO A SYSTEM OF   APP00340
C                                         AXES PARALLEL AND NORMAL TO   APP00350
C                                         PITCH-REFERENCE LINE WITH ORI-APP00360
C                                         GIN AT THE CENTROID OF THE    APP0C370
C                                         SECTION (FEET)                APP0C380
C                        COMMON/VALU2/    ORDINATE OF CRITICAL POINT NO.APP0C390
C                                         2 ON BLADE SECTION PERIPHERY  APP0C400
C                                         WITH RESPECT TO A SYSTEM OF   APP0C410
C                                         AXES PARALLEL AND NORMAL TO   APP00420
C                                         PITCH-REFERENCE LINE WITH ORI-APP0C430
C                                         GIN AT THE CENTROID OF THE    APP0C440
C                                         SECTION (FEET)                APP0C450
C                        COMMON/VALW2/    ABCISSA OF CRITICAL POINT NO. APP0C460
C                                         2 ON BLADE SECTION PERIPHERY  APP0C470
C                                         WITH RESPECT TO A SYSTEM OF   APP0C480
```

```
C                                                                       APP00490
C                                     AXES PARALLEL AND NORMAL TO       APP00500
C                                     PITCH-REFERENCE LINE WITH ORI-    APP00510
C                                     GIN AT THE CENTROID OF THE        APP00520
C                                     SECTION (FEET)                    APP00530
C                  COMMON/VALU3/      ORDINATE OF CRITICAL POINT NO.    APP00540
C                                     3 ON BLADE SECTION PERIPHERY      APP00550
C                                     WITH RESPECT TO A SYSTEM OF       APP00560
C                                     AXES PARALLEL AND NORMAL TO       APP00570
C                                     PITCH-REFERENCE LINE WITH ORI-    APP00580
C                                     GIN AT THE CENTROID OF THE        APP00590
C                  COMMON/VALW3/      ABCISSA OF CRITICAL POINT NO.     APP00600
C                                     3 ON BLADE SECTION PERIPHERY      APP00610
C                                     WITH RESPECT TO A SYSTEM OF       APP00620
C                                     AXES PARALLEL AND NORMAL TO       APP00630
C                                     PITCH-REFERENCE LINE WITH ORI-    APP00640
C                                     GIN AT THE CENTROID OF THE        APP00650
C                                     SECTION (FEET)                    APP00660
C                  COMMON/VALU4/      ORDINATE OF CRITICAL POINT NO.    APP00670
C                                     4 ON BLADE SECTION PERIPHERY      APP00680
C                                     WITH RESPECT TO A SYSTEM OF       APP00690
C                                     AXES PARALLEL AND NORMAL TO       APP00700
C                                     PITCH-REFERENCE LINE WITH ORI-    APP00710
C                                     GIN AT THE CENTROID OF THE        APP00720
C                                     SECTION (FEET)                    APP00730
C                  COMMON/VALW4/      ABCISSA OF CRITICAL POINT NO.     APP00740
C                                     4 ON BLADE SECTION PERIPHERY      APP00750
C                                     WITH RESPECT TO A SYSTEM OF       APP00760
C                                     AXES PARALLEL AND NORMAL TO       APP00770
C                                     PITCH-REFERENCE LINE WITH ORI-    APP00780
C                                     GIN AT THE CENTROID OF THE        APP00790
C                                     SECTION (FEET)                    APP00800
C                  COMMON/A2MOMX/     MOMENT OF INERTIA ABOUT NEU-      APP00810
C                                     TRAL AXIS PARALLEL TO GENERA-     APP00820
C                                     TOR LINE, PASSING THROUGH         APP00830
C                                     BLADE CROSS SECTION CENTROID      APP00840
C                                     (FEET**4)                         APP00850
C                  COMMON/A2MOMY/     MOMENT OF INERTIA ABOUT NEU-      APP00860
C                                     TRAL AXIS PARALLEL TO PITCH       APP00870
C                                     REFERENCE LINE,PASSING THROUGH    APP00880
C                                     BLADE CROSS SECTION CENTROID      APP00890
C                                     (FEET**4)                         APP00900
C                                                                       APP00910
      REAL*4 ETAO,WEIGHT,AEOVAO,DIA,N,PE,PDIVD,QS,TC75R,V,              APP00920
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP00930
     2       FCWBAL,DIACNU,AEAOCV,TCSTRS,                               APP00940
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,               APP00950
     4       PWATVA,PROMAT,DIALIM,ETARR,                                APP00960
```

```
     5        RJ,C75R,R75R,KT,KQ                                                    APP01370
      REAL*4  T00R,T1XR,T20R,T30R,T40R,T50R,T60R,T70R,T75R,T80R,T90R,               APP01380
     1        T100R,RAT                                                             APP01390
      REAL*4  CR(10),AR(10),BR(10),PLF(10),PLA(10),TR(10),V1F(10,11),              APP01400
     1        V2F(10,11),V1A(10,10),V2A(10,10),YFACE(11),YBACK(11),                APP01410
     2        FA(10),Y(11),DELPA(10),AA(10),DLPASM,XA(10),YA(10),SUMAA,            APP01420
     3        SUMAXA,SUMAYA,SMAX2A,SMAY2A,FF(11),DELPF(11),AF(11),DLPFSM,          APP01430
     4        XF(11),YF(11),SUMAF,SUMAXF,SUMAYF,SMAX2F,SMAY2F,AREA(10),            APP01440
     5        XMT(10),YPRL(10),RIXXNA(10),RIYYNA(10),XCG(10),YCG(10)               APP01450
      REAL*4  U1(10),U2(10),U3(10),U4(10),W1(10),W2(10),W3(10),W4(10),             APP01460
     1        YBK,YFC,DN                                                            APP01470
      INTEGER*4 I,IR,IP1                                                          APP01480
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,EDIVD,QS,TC75R,V,RJCNL,          APP01490
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,              APP01500
     2AEACCV,TCSTRS,RJ                                                            APP01510
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA,           APP01520
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                        APP01530
      COMMON /THICD/T00R,T1XR,T20R,T30R,T40R,T50R,T60R,T70R,T75R,T80R,             APP01540
     1T90R,T100R,RAT                                                              APP01550
      COMMON /AREELD/AREA                                                         APP01560
      COMMON /CGX/XCG                                                             APP01570
      COMMON /CGY/YCG                                                             APP01580
      COMMON /CRDINT/CR                                                           APP01590
      COMMON /VALL1/U1                                                            APP01600
      COMMON /VALL2/U2                                                            APP01610
      COMMON /VALL3/U3                                                            APP01620
      COMMON /VALL4/U4                                                            APP01630
      COMMON /VALW1/W1                                                            APP01640
      COMMON /VALW2/W2                                                            APP01650
      COMMON /VALW3/W3                                                            APP01660
      COMMON /VALW4/W4                                                            APP01670
      COMMON /A2MCMX/RIYYNA                                                       APP01680
      COMMON /A2MCMY/RIXXNA                                                       APP01690
C                                                                                 APP01700
CCC   DETERMINE CHORD LENGTHS ALONG BLADE RADIUS USING TABLE (1), REF 2           APP01710
C                                                                                 APP01720
      IF(.NOT.(Z.EQ.3.0))GO TO 1                                                  APP01730
           CR(I)=(1.5932*AEDVAO*DIA)/Z                                            APP01740
      GO TO 5                                                                     APP01750
    1 CONTINUE                                                                    APP01760
      IF(.NOT.(Z.EQ.4.0))GO TO 2                                                  APP01770
           CR(I)=(1.5894*AEDVAO*DIA)/Z                                            APP01780
      GO TO 5                                                                     APP01790
    2 CONTINUE                                                                    APP01800
      IF(.NOT.(Z.EQ.5.0))GO TO 3                                                  APP01810
           CR(I)=(1.5894*AEDVAO*DIA)/Z                                            APP01820
      GO TO 5                                                                     APP01830
    3 CONTINUE                                                                    APP01840
```

```
      IF(.NOT.(Z.EQ.6.0))GO TO 4                                        APP01450
           CR(1)=(1.5894*AEDVAO*DIA)/2                                  APP01460
      GO TO 5                                                           APP01470
    4 CONTINUE                                                          APP01480
           CR(1)=(1.6180*AEDVAO*DIA)/2                                  APP01490
    5 CONTINUE                                                          APP01500
      IF(.NOT.(Z.EQ.3.0))GO TO 6                                        APP01510
           CR(2)=(1.6330*AEDVAO*DIA)/2                                  APP01520
           CR(3)=(1.8320*AEDVAO*DIA)/2                                  APP01530
           CR(4)=(2.0000*AEDVAO*DIA)/2                                  APP01540
           CR(5)=(2.1200*AEDVAO*DIA)/2                                  APP01550
           CR(6)=(2.1860*AEDVAO*DIA)/2                                  APP01560
           CR(7)=(2.1680*AEDVAO*DIA)/2                                  APP01570
           CR(8)=(2.1270*AEDVAO*DIA)/2                                  APP01580
           CR(9)=(1.6570*AEDVAO*DIA)/2                                  APP01590
           CR(10)=(0.000*AEDVAO*DIA)/2                                  APP01600
      GO TO 7                                                           APP01610
    6 CONTINUE                                                          APP01620
           CR(2)=(1.6620*AEDVAO*DIA)/2                                  APP01630
           CR(3)=(1.8820*AEDVAO*DIA)/2                                  APP01640
           CR(4)=(2.0500*AEDVAO*DIA)/2                                  APP01650
           CR(5)=(2.1520*AEDVAO*DIA)/2                                  APP01660
           CR(6)=(2.1870*AEDVAO*DIA)/2                                  APP01670
           CR(7)=(2.1440*AEDVAO*DIA)/2                                  APP01680
           CR(8)=(1.9700*AEDVAO*DIA)/2                                  APP01690
           CR(9)=(1.5820*AEDVAO*DIA)/2                                  APP01700
           CR(10)=(0.000*AEDVAO*DIA)/2                                  APP01710
    7 CONTINUE                                                          APP01720
C                                                                       APP01730
CC    CALCULATE POSITION OF GENERATOR LINE (I.E., AR(I)) AND POSITION OF APP01740
CC    MAXIMUM BLADE SECTION THICKNESS (I.E., BR(I)) USING FIGURE (1) AND APP01750
CC    TABLE (1), REF 2                                                  APP01760
C                                                                       APP01770
      IF(.NOT.(Z.EQ.3.0))GO TO 8                                        APP01780
           AR(1)=0.617*CR(1)                                            APP01790
           BR(1)=0.350*CR(1)                                            APP01800
      GO TO 12                                                          APP01810
    8 CONTINUE                                                          APP01820
      IF(.NOT.(Z.EQ.4.0))GO TO 9                                        APP01830
           AR(1)=0.61832*CR(1)                                          APP01840
           BR(1)=0.350*CR(1)                                            APP01850
      GO TO 12                                                          APP01860
    9 CONTINUE                                                          APP01870
      IF(.NOT.(Z.EQ.5.0))GO TO 10                                       APP01880
           AR(1)=0.61832*CR(1)                                          APP01890
           BR(1)=0.350*CR(1)                                            APP01900
      GO TO 12                                                          APP01910
   10 CONTINUE                                                          APP01920
```

```
      IF(.NOT.(Z.EQ.6.0))GO TO 11                                       APP01530
            AR(1)=C.6182*CR(1)                                          APP01540
            BR(1)=C.350*CR(1)                                           APP01550
      GO TO 12                                                          APP01560
   11 CONTINUE                                                          APP01570
            AR(1)=C.6178*CR(1)                                          APP01580
            BR(1)=C.350*CR(1)                                           APP01590
   12 CONTINUE                                                          APP02000
      IF(.NOT.(Z.EQ.3.0))GO TO 13                                       APP02010
            AR(2)=C.616*CR(2)                                           APP02020
            AR(3)=C.611*CR(3)                                           APP02030
            AR(4)=C.595*CR(4)                                           APP02040
            AR(5)=C.583*CR(5)                                           APP02050
            AR(6)=C.558*CR(6)                                           APP02060
            AR(7)=C.526*CR(7)                                           APP02070
            AR(8)=C.481*CR(8)                                           APP02080
            AR(9)=C.400*CR(9)                                           APP02090
            AR(10)=0.0                                                  APP02100
            BR(2)=C.350*CR(2)                                           APP02110
            BR(3)=C.350*CR(3)                                           APP02120
            BR(4)=C.350*CR(4)                                           APP02130
            BR(5)=C.355*CR(5)                                           APP02140
            BR(6)=C.389*CR(6)                                           APP02150
            BR(7)=C.442*CR(7)                                           APP02160
            BR(8)=C.478*CR(8)                                           APP02170
            BR(9)=C.500*CR(9)                                           APP02180
            BR(10)=0.0                                                  APP02190
      GO TO 14                                                          APP02200
   13 CONTINUE                                                          APP02210
            AR(2)=C.617*CR(2)                                           APP02220
            AR(3)=C.613*CR(3)                                           APP02230
            AR(4)=C.601*CR(4)                                           APP02240
            AR(5)=C.586*CR(5)                                           APP02250
            AR(6)=C.561*CR(6)                                           APP02260
            AR(7)=C.524*CR(7)                                           APP02270
            AR(8)=C.463*CR(8)                                           APP02280
            AR(9)=C.351*CR(9)                                           APP02290
            AR(10)=0.0                                                  APP02300
            BR(2)=C.350*CR(2)                                           APP02310
            BR(3)=C.350*CR(3)                                           APP02320
            BR(4)=C.351*CR(4)                                           APP02330
            BR(5)=C.355*CR(5)                                           APP02340
            BR(6)=C.389*CR(6)                                           APP02350
            BR(7)=C.443*CR(7)                                           APP02360
            BR(8)=C.479*CR(8)                                           APP02370
            BR(9)=C.500*CR(9)                                           APP02380
            BR(10)=0.0                                                  APP02390
   14 CONTINUE                                                          APP02400
```

```
C                                                                       APP02410
CC      DETERMINE "FORWARD" (P=0 TO P=+1) AND "AFT" (P=0 TO P=-1)       APP02420
CC      INTEGRATION INTERVALS WITH RESPECT TO PITCH-REFERENCE LINE FOR  APP02430
CC      EACH BLADE SECTION ALONG PROPELLER BLADE RADIUS USING FIGURE (1) APP02440
CC      AND TABLE (1), REF 2                                            APP02450
C                                                                       APP02460
        DO 15 I=1,10                                                    APP02470
             PLF(I)=BR(I)                                               APP02480
             PLA(I)=CR(I)-PLF(I)                                        APP02490
   15 CONTINUE                                                          APP02500
C                                                                       APP02510
CC      INITIALIZE MAXIMUM BLADE SECTION THICKNESS ALONG PROPELLER BLADE APP02520
CC      RADIUS                                                          APP02530
C                                                                       APP02540
        TR(1)=T1XR                                                      APP02550
        TR(2)=T2CR                                                      APP02560
        TR(3)=T3CR                                                      APP02570
        TR(4)=T4CR                                                      APP02580
        TR(5)=T5CR                                                      APP02590
        TR(6)=T6CR                                                      APP02600
        TR(7)=T7CR                                                      APP02610
        TR(8)=T8CR                                                      APP02620
        TR(9)=T9CR                                                      APP02630
        TR(10)=T10OR                                                    APP02640
C                                                                       APP02650
CC      INITIALIZE VALUES FOR "V1" & "V2" (P=0 TO P=+1) AND "V1" & "V2" APP02660
CC      (P=0 TO P=-1) IN RELATIONS (2) AND (3), REF 2, USING VALUES FROM APP02670
CC      TABLE (2), REF 2                                                APP02680
CC                                                                      APP02690
CC      ... BEGIN AT R=.18R FOR PROPELLERS WITH 3 OR 7 BLADES           APP02700
C                                                                       APP02710
        IF(.NOT.((Z.EQ.3.0).OR.(Z.EQ.7.0)))GO TO 16                     APP02720
             V1F(1,1)=0.0000                                            APP02730
             V1F(1,2)=0.0063                                            APP02740
             V1F(1,3)=0.0336                                            APP02750
             V1F(1,4)=0.0558                                            APP02760
             V1F(1,5)=0.0851                                            APP02770
             V1F(1,6)=0.1238                                            APP02780
             V1F(1,7)=0.1761                                            APP02790
             V1F(1,8)=0.2092                                            APP02800
             V1F(1,9)=0.2466                                            APP02810
             V1F(1,10)=0.2947                                           APP02820
             V1F(1,11)=0.3678                                           APP02830
             V1A(1,1)=0.0000                                            APP02840
             V1A(1,2)=0.0232                                            APP02850
             V1A(1,3)=0.0722                                            APP02860
             V1A(1,4)=0.1028                                            APP02870
             V1A(1,5)=0.1352                                            APP02880
```

```
                V1A(1,6)=0.1713                                                 APP02890
                V1A(1,7)=0.2098                                                 APP02900
                V1A(1,8)=0.2505                                                 APP02910
                V1A(1,9)=0.2715                                                 APPC2920
                V1A(1,10)=0.2905                                                APP02930
                V2F(1,1)=1.0000                                                 APP02940
                V2F(1,2)=0.9752                                                 APP02950
                V2F(1,3)=0.8860                                                 APPU2960
                V2F(1,4)=0.8126                                                 APP02970
                V2F(1,5)=0.7213                                                 APP02980
                V2F(1,6)=0.6116                                                 APP02990
                V2F(1,7)=0.4680                                                 APP03000
                V2F(1,8)=0.3813                                                 APP03010
                V2F(1,9)=0.2749                                                 APP03020
                V2F(1,10)=0.1463                                                APP03030
                V2F(1,11)=C.0000                                                APP03040
                V2A(1,1)=1.0000                                                 APPJ3050
                V2A(1,2)=0.9414                                                 APP03060
                V2A(1,3)=0.7915                                                 APP03070
                V2A(1,4)=0.6909                                                 APP03080
                V2A(1,5)=0.5744                                                 APP03090
                V2A(1,6)=0.4438                                                 APP03100
                V2A(1,7)=0.2986                                                 APP03110
                V2A(1,8)=0.1406                                                 APP03120
                V2A(1,9)=0.0602                                                 APP03130
                V2A(1,10)=C.0000                                                APP03140
        GO TO 17                                                                APP03150
C                                                                               APP03160
CC      ... OR BEGIN AT R=.167R FOR PROPELLERS WITH 4,5,OR 6 BLADES             APP03170
C                                                                               APP03180
    16 CONTINUE                                                                 APP03190
                V1F(1,1)=0.0000                                                 APP03200
                V1F(1,2)=0.0076                                                 APP03210
                V1F(1,3)=0.0357                                                 APP03220
                V1F(1,4)=0.0529                                                 APP03230
                V1F(1,5)=0.0881                                                 APPJ3240
                V1F(1,6)=0.1274                                                 APPJ3250
                V1F(1,7)=0.1808                                                 APP03260
                V1F(1,8)=0.2152                                                 APPJ3270
                V1F(1,9)=0.2541                                                 APP03280
                V1F(1,10)=0.3033                                                APP03290
                V1F(1,11)=C.3756                                                APP03300
                V1A(1,1)=0.0000                                                 APP03310
                V1A(1,2)=0.0282                                                 APP03320
                V1A(1,3)=0.0817                                                 APPJ3330
                V1A(1,4)=0.1134                                                 APP03340
                V1A(1,5)=0.1457                                                 APPJ3350
                V1A(1,6)=0.1812                                                 APPJ3360
```

```
      V1A(1,7)=0.2184                                                   APP03370
      V1A(1,8)=0.2569                                                   APP03380
      V1A(1,9)=0.2764                                                   APP03390
      V1A(1,10)=0.2946                                                  APP03400
      V2F(1,1)=1.0000                                                   APP03410
      V2F(1,2)=0.9754                                                   APP03420
      V2F(1,3)=0.8847                                                   APP03430
      V2F(1,4)=0.8056                                                   APP03440
      V2F(1,5)=0.7167                                                   APP03450
      V2F(1,6)=0.6065                                                   APP03460
      V2F(1,7)=0.4613                                                   APP03470
      V2F(1,8)=0.3751                                                   APP03480
      V2F(1,9)=0.2686                                                   APP03490
      V2F(1,10)=0.1395                                                  APP03500
      V2F(1,11)=0.0000                                                  APP03510
      V2A(1,1)=1.0000                                                   APP03520
      V2A(1,2)=0.9391                                                   APP03530
      V2A(1,3)=0.7868                                                   APP03540
      V2A(1,4)=0.6850                                                   APP03550
      V2A(1,5)=0.5676                                                   APP03560
      V2A(1,6)=0.4372                                                   APP03570
      V2A(1,7)=0.2936                                                   APP03580
      V2A(1,8)=0.1372                                                   APP03590
      V2A(1,9)=0.0576                                                   APP03600
      V2A(1,10)=0.0000                                                  APP03610
   17 CONTINUE                                                          APP03620
C                                                                       APP03630
CC       ... CONTINUE FOR R=.2R                                         APP03640
C                                                                       APP03650
      V1F(2,1)=0.0000                                                   APP03660
      V1F(2,2)=0.0049                                                   APP03670
      V1F(2,3)=0.0304                                                   APP03680
      V1F(2,4)=0.0502                                                   APP03690
      V1F(2,5)=0.0804                                                   APP03700
      V1F(2,6)=0.1180                                                   APP03710
      V1F(2,7)=0.1685                                                   APP03720
      V1F(2,8)=0.2000                                                   APP03730
      V1F(2,9)=0.2353                                                   APP03740
      V1F(2,10)=0.2821                                                  APP03750
      V1F(2,11)=0.3560                                                  APP03760
      V1A(2,1)=0.0000                                                   APP03770
      V1A(2,2)=0.0172                                                   APP03780
      V1A(2,3)=0.0592                                                   APP03790
      V1A(2,4)=0.0880                                                   APP03800
      V1A(2,5)=0.1207                                                   APP03810
      V1A(2,6)=0.1570                                                   APP03820
      V1A(2,7)=0.1967                                                   APP03830
      V1A(2,8)=0.2400                                                   APP03840
```

```
      V1A(2,9)=0.2630                                                   APP03850
      V1A(2,10)=0.2826                                                  APP03860
      V2F(2,1)=1.0000                                                   APP03870
      V2F(2,2)=0.9750                                                   APP03880
      V2F(2,3)=0.8875                                                   APP03890
      V2F(2,4)=0.8170                                                   APP03900
      V2F(2,5)=0.7277                                                   APP03910
      V2F(2,6)=0.6190                                                   APP03920
      V2F(2,7)=0.4777                                                   APP03930
      V2F(2,8)=0.3905                                                   APP03940
      V2F(2,9)=0.2840                                                   APP03950
      V2F(2,10)=0.1560                                                  APP03960
      V2F(2,11)=0.0000                                                  APP03970
      V2A(2,1)=1.0000                                                   APP03980
      V2A(2,2)=0.9446                                                   APP03990
      V2A(2,3)=0.7984                                                   APP04000
      V2A(2,4)=0.6995                                                   APP04010
      V2A(2,5)=0.5842                                                   APP04020
      V2A(2,6)=0.4535                                                   APP04030
      V2A(2,7)=0.3060                                                   APP04040
      V2A(2,8)=0.1455                                                   APP04050
      V2A(2,9)=0.0640                                                   APP04060
      V2A(2,10)=0.0000                                                  APP04070
C                                                                       APP04080
C     ... CONTINUE FOR R=.3R                                            APP04090
C                                                                       APP04100
      V1F(3,1)=0.0000                                                   APP04110
      V1F(3,2)=0.0027                                                   APP04120
      V1F(3,3)=0.0148                                                   APP04130
      V1F(3,4)=0.0300                                                   APP04140
      V1F(3,5)=0.0503                                                   APP04150
      V1F(3,6)=0.0709                                                   APP04160
      V1F(3,7)=0.1191                                                   APP04170
      V1F(3,8)=0.1445                                                   APP04180
      V1F(3,9)=0.1760                                                   APP04190
      V1F(3,10)=0.2186                                                  APP04200
      V1F(3,11)=0.2923                                                  APP04210
      V1A(3,1)=0.0000                                                   APP04220
      V1A(3,2)=0.0033                                                   APP04230
      V1A(3,3)=0.0202                                                   APP04240
      V1A(3,4)=0.0376                                                   APP04250
      V1A(3,5)=0.0623                                                   APP04260
      V1A(3,6)=0.0943                                                   APP04270
      V1A(3,7)=0.1333                                                   APP04280
      V1A(3,8)=0.1790                                                   APP04290
      V1A(3,9)=0.2040                                                   APP04300
      V1A(3,10)=0.2306                                                  APP04310
      V2F(3,1)=1.0000                                                   APP04320
```

```
      V2F(3,2)=C.9750                                                   APP04330
      V2F(3,3)=0.8920                                                   APP04340
      V2F(3,4)=C.8315                                                   APP04350
      V2F(3,5)=C.7520                                                   APP04360
      V2F(3,6)=C.6505                                                   APP04370
      V2F(3,7)=C.5130                                                   APP04380
      V2F(3,8)=C.4265                                                   APP04390
      V2F(3,9)=0.3197                                                   APP04400
      V2F(3,10)=0.1890                                                  APP04410
      V2F(3,11)=0.0000                                                  APP04420
      V2A(3,1)=1.0000                                                   APP04430
      V2A(3,2)=C.9583                                                   APP04440
      V2A(3,3)=0.8265                                                   APP04450
      V2A(3,4)=C.7335                                                   APP04460
      V2A(3,5)=0.6195                                                   APP04470
      V2A(3,6)=C.4885                                                   APP04480
      V2A(3,7)=C.3360                                                   APP04490
      V2A(3,8)=0.1670                                                   APP04500
      V2A(3,9)=C.0800                                                   APP04510
      V2A(3,10)=0.0000                                                  APP04520
C                                                                       APP04530
C     ... CONTINUE FOR R=.4R                                            APP04540
C                                                                       APP04550
      V1F(4,1)=0.0000                                                   APP04560
      V1F(4,2)=C.0000                                                   APP04570
      V1F(4,3)=0.0033                                                   APP04580
      V1F(4,4)=0.0090                                                   APP04590
      V1F(4,5)=0.0189                                                   APP04600
      V1F(4,6)=0.0357                                                   APP04610
      V1F(4,7)=0.0637                                                   APP04620
      V1F(4,8)=0.0833                                                   APP04630
      V1F(4,9)=0.1088                                                   APP04640
      V1F(4,10)=0.1467                                                  APP04650
      V1F(4,11)=0.2181                                                  APP04660
      V1A(4,1)=0.0000                                                   APP04670
      V1A(4,2)=0.0000                                                   APP04680
      V1A(4,3)=0.0044                                                   APP04690
      V1A(4,4)=0.0116                                                   APP04700
      V1A(4,5)=0.0214                                                   APP04710
      V1A(4,6)=0.0395                                                   APP04720
      V1A(4,7)=0.0630                                                   APP04730
      V1A(4,8)=0.0972                                                   APP04740
      V1A(4,9)=C.1200                                                   APP04750
      V1A(4,10)=0.1467                                                  APP04760
      V2F(4,1)=1.0000                                                   APP04770
      V2F(4,2)=C.9725                                                   APP04780
      V2F(4,3)=0.8933                                                   APP04790
      V2F(4,4)=0.8345                                                   APP04800
```

```
      V2F(4,5)=C.1593                                                   APPC4810
      V2F(4,6)=0.0590                                                   APPC4820
      V2F(4,7)=C.0220                                                   APPC4830
      V2F(4,8)=C.0335                                                   APPC4840
      V2F(4,9)=0.0235                                                   APPC4850
      V2F(4,10)=0.1935                                                  APPC4860
      V2F(4,11)=0.0000                                                  APPC4870
      V2A(4,1)=1.0000                                                   APPC4880
      V2A(4,2)=C.0645                                                   APPC4890
      V2A(4,3)=C.0415                                                   APPC4900
      V2A(4,4)=C.0525                                                   APPC4910
      V2A(4,5)=C.0353                                                   APPC4920
      V2A(4,6)=0.0040                                                   APPC4930
      V2A(4,7)=C.0500                                                   APPC4940
      V2A(4,8)=0.1810                                                   APPC4950
      V2A(4,9)=C.0905                                                   APPC4960
      V2A(4,10)=0.0000                                                  APPC4970
C                                                                       APPC4980
C     ... CONTINUE FOR R=.5R                                            APPC4990
C                                                                       APPC5000
      V1F(5,1)=C.0000                                                   APPC5010
      V1F(5,2)=C.0000                                                   APPC5020
      V1F(5,3)=0.0000                                                   APPC5030
      V1F(5,4)=0.0008                                                   APPC5040
      V1F(5,5)=0.0034                                                   APPC5050
      V1F(5,6)=0.0085                                                   APPC5060
      V1F(5,7)=0.0211                                                   APPC5070
      V1F(5,8)=0.0328                                                   APPC5080
      V1F(5,9)=0.0500                                                   APPC5090
      V1F(5,10)=0.0776                                                  APPC5100
      V1F(5,11)=0.1278                                                  APPC5110
      V1A(5,1)=0.0000                                                   APPC5120
      V1A(5,2)=0.0000                                                   APPC5130
      V1A(5,3)=0.0000                                                   APPC5140
      V1A(5,4)=0.0012                                                   APPC5150
      V1A(5,5)=0.0040                                                   APPC5160
      V1A(5,6)=0.0100                                                   APPC5170
      V1A(5,7)=C.0190                                                   APPC5180
      V1A(5,8)=0.0330                                                   APPC5190
      V1A(5,9)=0.0420                                                   APPC5200
      V1A(5,10)=0.0522                                                  APPC5210
      V2F(5,1)=1.0000                                                   APPC5220
      V2F(5,2)=C.0710                                                   APPC5230
      V2F(5,3)=0.0880                                                   APPC5240
      V2F(5,4)=C.0275                                                   APPC5250
      V2F(5,5)=C.1478                                                   APPC5260
      V2F(5,6)=0.0430                                                   APPC5270
      V2F(5,7)=0.5039                                                   APPC5280
```

```
      V2F(5,8)=0.4135                                                   APP05290
      V2F(5,9)=0.3056                                                   APP05300
      V2F(5,10)=0.1750                                                  APP05310
      V2F(5,11)=0.0000                                                  APP05320
      V2A(5,1)=1.0000                                                   APP05330
      V2A(5,2)=0.9639                                                   APP05340
      V2A(5,3)=0.8456                                                   APP05350
      V2A(5,4)=0.7580                                                   APP05360
      V2A(5,5)=0.6439                                                   APP05370
      V2A(5,6)=0.5140                                                   APP05380
      V2A(5,7)=0.3569                                                   APP05390
      V2A(5,8)=0.1865                                                   APP05400
      V2A(5,9)=0.0950                                                   APP05410
      V2A(5,10)=0.0000                                                  APP05420
C                                                                       APP05430
C     ... CONTINUE FOR R=.6R                                            APP05440
C                                                                       APP05450
      V1F(6,1)=0.0000                                                   APP05460
      V1F(6,2)=0.0000                                                   APP05470
      V1F(6,3)=0.0000                                                   APP05480
      V1F(6,4)=0.0000                                                   APP05490
      V1F(6,5)=0.0000                                                   APP05500
      V1F(6,6)=0.0000                                                   APP05510
      V1F(6,7)=0.0006                                                   APP05520
      V1F(6,8)=0.0022                                                   APP05530
      V1F(6,9)=0.0067                                                   APP05540
      V1F(6,10)=0.0169                                                  APP05550
      V1F(6,11)=0.0382                                                  APP05560
      V1A(6,1)=0.0000                                                   APP05570
      V1A(6,2)=0.0000                                                   APP05580
      V1A(6,3)=0.0000                                                   APP05590
      V1A(6,4)=0.0000                                                   APP05600
      V1A(6,5)=0.0000                                                   APP05610
      V1A(6,6)=0.0000                                                   APP05620
      V1A(6,7)=0.0000                                                   APP05630
      V1A(6,8)=0.0000                                                   APP05640
      V1A(6,9)=0.0000                                                   APP05650
      V1A(6,10)=0.0000                                                  APP05660
      V2F(6,1)=1.0000                                                   APP05670
      V2F(6,2)=0.9690                                                   APP05680
      V2F(6,3)=0.8790                                                   APP05690
      V2F(6,4)=0.8090                                                   APP05700
      V2F(6,5)=0.7200                                                   APP05710
      V2F(6,6)=0.6060                                                   APP05720
      V2F(6,7)=0.4620                                                   APP05730
      V2F(6,8)=0.3775                                                   APP05740
      V2F(6,9)=0.2720                                                   APP05750
      V2F(6,10)=0.1485                                                  APP05760
```

```
      V2F(6,11)=0.0000                                                  APP05770
      V2A(6,1)=1.0000                                                   APP05780
      V2A(6,2)=0.9613                                                   APP05790
      V2A(6,3)=0.8426                                                   APP05800
      V2A(6,4)=0.7530                                                   APP05810
      V2A(6,5)=0.6415                                                   APP05820
      V2A(6,6)=0.5110                                                   APP05830
      V2A(6,7)=0.3585                                                   APP05840
      V2A(6,8)=0.1885                                                   APP05850
      V2A(6,9)=0.0965                                                   APP05860
      V2A(6,10)=0.0000                                                  APP05870
C                                                                       APP05880
C     ... CONTINUE FOR R=.7R                                            APP05890
C                                                                       APP05900
      V1F(7,1)=0.0000                                                   APP05910
      V1F(7,2)=0.0000                                                   APP05920
      V1F(7,3)=0.0000                                                   APP05930
      V1F(7,4)=0.0000                                                   APP05940
      V1F(7,5)=0.0000                                                   APP05950
      V1F(7,6)=0.0000                                                   APP05960
      V1F(7,7)=0.0000                                                   APP05970
      V1F(7,8)=0.0000                                                   APP05980
      V1F(7,9)=0.0000                                                   APP05990
      V1F(7,10)=0.0000                                                  APP06000
      V1F(7,11)=0.0000                                                  APP06010
      V1A(7,1)=0.0000                                                   APP06020
      V1A(7,2)=0.0000                                                   APP06030
      V1A(7,3)=0.0000                                                   APP06040
      V1A(7,4)=0.0000                                                   APP06050
      V1A(7,5)=0.0000                                                   APP06060
      V1A(7,6)=0.0000                                                   APP06070
      V1A(7,7)=0.0000                                                   APP06080
      V1A(7,8)=0.0000                                                   APP06090
      V1A(7,9)=0.0000                                                   APP06100
      V1A(7,10)=0.0000                                                  APP06110
      V2F(7,1)=1.0000                                                   APP06120
      V2F(7,2)=0.9675                                                   APP06130
      V2F(7,3)=0.8660                                                   APP06140
      V2F(7,4)=0.7850                                                   APP06150
      V2F(7,5)=0.6840                                                   APP06160
      V2F(7,6)=0.5615                                                   APP06170
      V2F(7,7)=0.4140                                                   APP06180
      V2F(7,8)=0.2300                                                   APP06190
      V2F(7,9)=0.2337                                                   APP06200
      V2F(7,10)=0.1240                                                  APP06210
      V2F(7,11)=0.0000                                                  APP06220
      V2A(7,1)=1.0000                                                   APP06230
      V2A(7,2)=0.9600                                                   APP06240
```

```
      V2A(7,3)=C.6400                                                   APP06250
      V2A(7,4)=C.7500                                                   APP06260
      V2A(7,5)=C.6400                                                   APP06270
      V2A(7,6)=C.6100                                                   APP06280
      V2A(7,7)=C.5600                                                   APP06290
      V2A(7,8)=C.1900                                                   APP06300
      V2A(7,9)=0.0975                                                   APP06310
      V2A(7,10)=0.0000                                                  APP06320
C                                                                       APP06330
C     ... CONTINUE FOR R=.8R                                            APP06340
C                                                                       APP06350
      V1F(8,1)=0.0000                                                   APP06360
      V1F(8,2)=0.0000                                                   APP06370
      V1F(8,3)=0.0000                                                   APP06380
      V1F(8,4)=0.0000                                                   APP06390
      V1F(8,5)=0.0000                                                   APP06400
      V1F(8,6)=0.0000                                                   APP06410
      V1F(8,7)=0.0000                                                   APP06420
      V1F(8,8)=0.0000                                                   APP06430
      V1F(8,9)=0.0000                                                   APP06440
      V1F(8,10)=0.0000                                                  APP06450
      V1F(8,11)=0.0000                                                  APP06460
      V1A(8,1)=0.0000                                                   APP06470
      V1A(8,2)=0.0000                                                   APP06480
      V1A(8,3)=0.0000                                                   APP06490
      V1A(8,4)=0.0000                                                   APP06500
      V1A(8,5)=0.0000                                                   APP06510
      V1A(8,6)=0.0000                                                   APP06520
      V1A(8,7)=0.0000                                                   APP06530
      V1A(8,8)=0.0000                                                   APP06540
      V1A(8,9)=0.0000                                                   APP06550
      V1A(8,10)=0.0000                                                  APP06560
      V2F(8,1)=1.0000                                                   APP06570
      V2F(8,2)=0.9635                                                   APP06580
      V2F(8,3)=0.8520                                                   APP06590
      V2F(8,4)=0.7635                                                   APP06600
      V2F(8,5)=0.6545                                                   APP06610
      V2F(8,6)=0.5265                                                   APP06620
      V2F(8,7)=0.3765                                                   APP06630
      V2F(8,8)=0.2925                                                   APP06640
      V2F(8,9)=0.2028                                                   APP06650
      V2F(8,10)=0.1050                                                  APP06660
      V2F(8,11)=0.0000                                                  APP06670
      V2A(8,1)=1.0000                                                   APP06680
      V2A(8,2)=0.9600                                                   APP06690
      V2A(8,3)=0.8400                                                   APP06700
      V2A(8,4)=0.7500                                                   APP06710
      V2A(8,5)=0.6400                                                   APP06720
```

```
      V2A(8,6)=C.5100                                                   APP06730
      V2A(8,7)=C.3600                                                   APP06740
      V2A(8,8)=C.1900                                                   APP06750
      V2A(8,9)=0.0975                                                   APP06760
      V2A(8,10)=0.0000                                                  APP06770
C                                                                       APP06780
C     ... CONTINUE FOR R=.9R                                            APP06790
C                                                                       APP06800
      V1F(9,1)=0.0000                                                   APP06810
      V1F(9,2)=0.0000                                                   APP06820
      V1F(9,3)=0.0000                                                   APP06830
      V1F(9,4)=0.0000                                                   APP06840
      V1F(9,5)=0.0000                                                   APP06850
      V1F(9,6)=0.0000                                                   APP06860
      V1F(9,7)=0.0000                                                   APP06870
      V1F(9,8)=0.0000                                                   APP06880
      V1F(9,9)=0.0000                                                   APP06890
      V1F(9,10)=0.0000                                                  APP06900
      V1F(9,11)=0.0000                                                  APP06910
      V1A(9,1)=0.0000                                                   APP06920
      V1A(9,2)=0.0000                                                   APP06930
      V1A(9,3)=0.0000                                                   APP06940
      V1A(9,4)=0.0000                                                   APP06950
      V1A(9,5)=0.0000                                                   APP06960
      V1A(9,6)=0.0000                                                   APP06970
      V1A(9,7)=0.0000                                                   APP06980
      V1A(9,8)=0.0000                                                   APP06990
      V1A(9,9)=0.0000                                                   APP07000
      V1A(9,10)=0.0000                                                  APP07010
      V2F(9,1)=1.0000                                                   APP07020
      V2F(9,2)=0.9600                                                   APP07030
      V2F(9,3)=0.8400                                                   APP07040
      V2F(9,4)=0.7500                                                   APP07050
      V2F(9,5)=0.6400                                                   APP07060
      V2F(9,6)=0.5100                                                   APP07070
      V2F(9,7)=0.3600                                                   APP07080
      V2F(9,8)=0.2775                                                   APP07090
      V2F(9,9)=0.1900                                                   APP07100
      V2F(9,10)=0.0975                                                  APP07110
      V2F(9,11)=0.0000                                                  APP07120
      V2A(9,1)=1.0000                                                   APP07130
      V2A(9,2)=0.9600                                                   APP07140
      V2A(9,3)=0.8400                                                   APP07150
      V2A(9,4)=0.7500                                                   APP07160
      V2A(9,5)=0.6400                                                   APP07170
      V2A(9,6)=0.5100                                                   APP07180
      V2A(9,7)=0.3600                                                   APP07190
      V2A(9,8)=0.1900                                                   APP07200
```

```
      V2A(9,9)=0.0975                                                   APP07210
      V2A(9,10)=0.0000                                                  APP07220
C                                                                       APP07230
CC    ... CONTINUE FOR R=1.0R                                           APP07240
C                                                                       APP07250
      V1F(10,1)=0.0000                                                  APP07260
      V1F(10,2)=0.0000                                                  APP07270
      V1F(10,3)=0.0000                                                  APP07280
      V1F(10,4)=0.0000                                                  APP07290
      V1F(10,5)=0.0000                                                  APP07300
      V1F(10,6)=0.0000                                                  APP07310
      V1F(10,7)=0.0000                                                  APP07320
      V1F(10,8)=0.0000                                                  APP07330
      V1F(10,9)=0.0000                                                  APP07340
      V1F(10,10)=0.0000                                                 APP07350
      V1F(10,11)=0.0000                                                 APP07360
      V1A(10,1)=0.0000                                                  APP07370
      V1A(10,2)=0.0000                                                  APP07380
      V1A(10,3)=0.0000                                                  APP07390
      V1A(10,4)=0.0000                                                  APP07400
      V1A(10,5)=0.0000                                                  APP07410
      V1A(10,6)=0.0000                                                  APP07420
      V1A(10,7)=0.0000                                                  APP07430
      V1A(10,8)=0.0000                                                  APP07440
      V1A(10,9)=0.0000                                                  APP07450
      V1A(10,10)=0.0000                                                 APP07460
      V2F(10,1)=1.0000                                                  APP07470
      V2F(10,2)=0.9600                                                  APP07480
      V2F(10,3)=0.8400                                                  APP07490
      V2F(10,4)=0.7500                                                  APP07500
      V2F(10,5)=0.6400                                                  APP07510
      V2F(10,6)=0.5100                                                  APP07520
      V2F(10,7)=0.3600                                                  APP07530
      V2F(10,8)=0.2775                                                  APP07540
      V2F(10,9)=0.1900                                                  APP07550
      V2F(10,10)=0.0975                                                 APP07560
      V2F(10,11)=0.0000                                                 APP07570
      V2A(10,1)=1.0000                                                  APP07580
      V2A(10,2)=0.9600                                                  APP07590
      V2A(10,3)=0.8400                                                  APP07600
      V2A(10,4)=0.7500                                                  APP07610
      V2A(10,5)=0.6400                                                  APP07620
      V2A(10,6)=0.5100                                                  APP07630
      V2A(10,7)=0.3600                                                  APP07640
      V2A(10,8)=0.1900                                                  APP07650
      V2A(10,9)=0.0975                                                  APP07660
      V2A(10,10)=0.0000                                                 APP07670
C                                                                       APP07680
```

```
C       CALCULATE BLADE SECTION PROPERTIES ALONG PROPELLER BLADE RADIUS    APP07690
C       AT:                    R                    IR                     APP07700
C                           .167R OR .18R           1                      APP07710
C                           .20R                    2                      APP07720
C                           .30R                    3                      APP07730
C                           .40R                    4                      APP07740
C                           .50R                    5                      APP07750
C                           .60R                    6                      APP07760
C                           .70R                    7                      APP07770
C                           .80R                    8                      APP07780
C                           .90R                    9                      APP07790
C                          1.00R                   10                      APP07800
C                                                                          APP07810
        DO 52 IR=1,10                                                      APP07820
CC                                                                         APP07830
CC          ... INITIALIZE SUMMATION VARIABLES TO ZERO FOR EACH ITERATION  APP07840
CC                                                                         APP07850
            SUMAA=C.0                                                      APP07860
            SUMAXA=0.0                                                     APP07870
            SUMAYA=0.0                                                     APP07880
            SMAX2A=0.0                                                     APP07890
            SMAY2A=0.0                                                     APP07900
            SUMAF=C.0                                                      APP07910
            SUMAXF=0.0                                                     APP07920
            SUMAYF=0.0                                                     APP07930
            SMAX2F=0.0                                                     APP07940
            SMAY2F=0.0                                                     APP07950
            DLFASM=0.0                                                     APP07960
            DLFFSM=0.0                                                     APP07970
CC                                                                         APP07980
CC          ... BEGIN WITH "AFT" PORTION (P=0 TO P=-1) OF BLADE SECTION    APP07990
CC          AS DEPICTED IN FIGURE (1), REF 2                               APP08000
CC                                                                         APP08010
            DC 21 I=1,9                                                    APP08020
                IP1=I+1                                                    APP08030
                YFACE(I)=(V1A(IR,I))*(TR(IR)-(0.1*TR(IR)))                 APP08040
                YBACK(I)=((V1A(IR,I)+V2A(IR,I))*(TR(IR)-(0.1*TR(IR))))     APP08050
     1                    +(0.1*TR(IR))                                   APP08060
                HA(I)=YBACK(I)-YFACE(I)                                    APP08070
                Y(I)=(YBACK(I)+YFACE(I))/2.0                               APP08080
                YFACE(IP1)=(V1A(IR,IP1))*(TR(IR)-(0.1*TR(IR)))             APP08090
                YBACK(IP1)=((V1A(IR,IP1)+V2A(IR,IP1))                      APP08100
     1                    *(TR(IR)-(0.1*TR(IR))))+(0.1*TR(IR))            APP08110
                HA(IP1)=YBACK(IP1)-YFACE(IP1)                              APP08120
                Y(IP1)=(YBACK(IP1)+YFACE(IP1))/2.C                         APP08130
                IF(.NOT.((I.EQ.1).OR.(I.EQ.2)))GO TO 18                    APP08140
                    DELPA(I)=(PLA(IR)/10.0)*2.0                            APP08150
                GC TO 20                                                   APP08160
```

```
   18          CONTINUE                                                          APP06170
               IF(.NOT.((I.EQ.8).OR.(I.EQ.9)))GO TO 19                           APP06180
                  DELPA(I)=(PLA(IR)/10.0)*0.5                                    APP06190
               GO TO 20                                                          APP06200
   19          CONTINUE                                                          APP06210
                  DELPA(I)=(PLA(IR)/10.0)*1.0                                    APP06220
   20          CONTINUE                                                          APP06230
               AA(I)=(0.5*(HA(IP1)+HA(I)))*DELPA(I)                              APP06240
               DLPASM=DLPASM+DELPA(I)                                            APP06250
               XA(I)=DLPASM-(DELPA(I)/2.0)                                       APP06260
               YA(I)=(Y(IP1)+Y(I))/2.0                                           APP06270
               SUMAA=SUMAA+AA(I)                                                 APP06280
               SUMAXA=SUMAXA+(AA(I)*XA(I))                                       APP06290
               SUMAYA=SUMAYA+(AA(I)*YA(I))                                       APP06300
               SMAX2A=SMAX2A+(AA(I)*((XA(I))**2))+                               APP06310
     1                ((1.0/12.0)*((HA(I)+HA(IP1))/2.0)*(DELPA(I)**3))          APP06320
               SMAY2A=SMAY2A+(AA(I)*((YA(I))**2))+                               APP06330
     1           ((1.0/12.0)*(DELPA(I))*(((HA(I)+HA(IP1))/2.0)**3))              APP06340
   21      CONTINUE                                                              APP06350
C                                                                                APP06360
C          ...CONTINUE WITH "FORWARD" PORTION (P=0 TO P=+1) OF BLADE             APP06370
C          SECTION AS DEPICTED IN FIGURE (1), REF 2                              APP06380
C                                                                                APP06390
           DO 25 I=1,10                                                          APP06400
               IP1=I+1                                                          APP06410
               YFACE(I)=(V1F(IR,I)*(TK(IR)-(0.1*TR(IR))))                       APP06420
               YBACK(I)=((V1F(IR,I)+V2F(IR,I))*(TR(IR)-(0.1*TR(IR))))           APP06430
     1                    +(0.1*TR(IR))                                         APP06440
               HF(I)=YBACK(I)-YFACE(I)                                          APP06450
               Y(I)=(YBACK(I)+YFACE(I))/2.0                                     APP06460
               YFACE(IP1)=(V1F(IR,IP1))*(TR(IR)-(0.1*TR(IR)))                   APP06470
               YBACK(IP1)=((V1F(IR,IP1)+V2F(IR,IP1))                            APP06480
     1                    *(TR(IR)-(0.1*TR(IR))))+(0.1*TR(IR))                  APP06490
               HF(IP1)=YBACK(IP1)-YFACE(IP1)                                    APP06500
               Y(IP1)=(YBACK(IP1)+YFACE(IP1))/2.0                               APP06510
               IF(.NOT.((I.EQ.1).OR.(I.EQ.2)))GO TO 22                          APP06520
                  DELPF(I)=(PLF(IR)/10.0)*2.0                                   APP06530
               GO TO 24                                                         APP06540
   22          CONTINUE                                                         APP06550
               IF(.NOT.((I.EQ.7).OR.(I.EQ.8).OR.(I.EQ.9).OR.(I.EQ.10)))APP06560
     1         GO TO 23                                                         APP06570
                  DELPF(I)=(PLF(IR)/10.0)*0.5                                   APP06580
               GO TO 24                                                         APP06590
   23          CONTINUE                                                         APP06600
                  DELPF(I)=(PLF(IR)/10.0)*1.0                                   APP06610
   24          CONTINUE                                                         APP06620
               AF(I)=(0.5*(HF(IP1)+HF(I)))*DELPF(I)                             APP06630
               DLPFSM=DLPFSM+DELPF(I)                                           APP06640
```

```
                XF(I)=DLPFSM-(DELPF(I)/2.0)                                     APP06650
                YF(I)=(Y(IP1)+Y(I))/2.0                                         APP06660
                SUMAF=SUMAF+AF(I)                                               APP06670
                SUMAXF=SUMAXF+(AF(I)*XF(I))                                     APP06680
                SUMAYF=SUMAYF+(AF(I)*YF(I))                                     APP06690
                SMAX2F=SMAX2F+(AF(I)*((XF(I))**2))+                             APP06700
     1                ((1.0/12.0)*((HF(I)+HF(IP1))/2.0)*(DELPF(I)**3))         APP06710
                SMAY2F=SMAY2F+(AF(I)*((YF(I))**2))+                             APP06720
     1          ((1.0/12.0)*(DELPF(I))*(((HF(I)+HF(IP1))/2.0)**3))            APP06730
  25        CONTINUE                                                            APP06740
C                                                                               APP06750
C       DETERMINE BLADE SECTION PROPERTIES, I.E., CROSS-SECTION AREA,           APP06760
C       AND AREA CENTROID LOCATION WITH RESPECT TO PITCH-REFERENCE              APP06770
C       LINE AND LINE OF MAXIMUM BLADE SECTION THICKNESS AS DEPICTED            APP06780
C       IN FIGURE (1), REF 2                                                    APP06790
C                                                                               APP06800
        AREA(IR)=SUMAA+SUMAF                                                    APP06810
        IF(.NOT.(AREA(IR).LE.0.0))GO TO 26                                      APP06820
             XMT(IR)=0.0                                                        APP06830
             YPRL(IR)=(DIA*(0.0030))/2.0                                        APP06840
        GO TO 27                                                                APP06850
  26    CONTINUE                                                                APP06860
             XMT(IR)=((SUMAXF)-(SUMAXA))/AREA(IR)                               APP06870
             YPRL(IR)=((SUMAYF)+(SUMAYA))/AREA(IR)                              APP06880
  27    CONTINUE                                                                APP06890
C                                                                               APP06900
C       CALCULATE MOMENT OF INERTIA WITH RESPECT TO NEUTRAL AXES                APP06910
C       USING PARALLEL AXIS THEOREM                                             APP06920
C                                                                               APP06930
        RIYYNA(IR)=((SMAX2F)+(SMAX2A))-                                         APP06940
     1             (((XMT(IR))**2)*AREA(IR))                                    APP06950
        RIXXNA(IR)=((SMAY2F)+(SMAY2A))-                                         APP06960
     1             (((YPRL(IR))**2)*AREA(IR))                                   APP06970
C                                                                               APP06980
C       DETERMINE LOCATION OF "CG" (I.E., NEUTRAL AXES ORIGIN) WITH             APP06990
C       RESPECT TO PITCH-REFERENCE LINE AND GENERATOR LINE DEPICTED             APP07000
C       IN FIGURE (1), REF2                                                     APP07010
C                                                                               APP07020
        IF(.NOT.(XMT(IR).LT.0.0))GO TO 28                                       APP07030
             DN=BR(IR)+ABS(XMT(IR))                                             APP07040
        GO TO 30                                                                APP07050
  28    CONTINUE                                                                APP07060
        IF(.NOT.(XMT(IR).GT.0.0))GO TO 29                                       APP07070
             DN=BR(IR)-ABS(XMT(IR))                                             APP07080
        GO TO 30                                                                APP07090
  29    CONTINUE                                                                APP07100
             DN=BR(IR)                                                          APP07110
  30    CONTINUE                                                                APP07120
```

```
      IF(.NOT.(DN.LT.AR(IR)))GO TO 31                                   APPOS130
          XCG(IR)=AR(IR)-DN                                             APPOS140
      GO TO 33                                                          APPOS150
   31 CONTINUE                                                          APPOS160
      IF(.NOT.(DN.GT.AR(IR)))GO TO 32                                   APPOS170
          XCG(IR)=-(DN-AR(IR))                                          APPOS180
      GO TO 33                                                          APPOS190
   32 CONTINUE                                                          APPOS200
          XCG(IR)=0.0                                                   APPOS210
   33 CONTINUE                                                          APPOS220
      YCG(IR)=YPRL(IR)                                                  APPOS230
C                                                                       APPOS240
C     DETERMINE "CRITICAL POINTS" OF A BLADE SECTION WITH RESPECT       APPOS250
C     TO NEUTRAL AXES WHERE STRESSES ARE LIKELY TO BE A MAXIMUM         APPOS260
C                                                                       APPOS270
C     ...CALCULATE ORDINATE (U2) AND ABCISSA (W2) OF CRITICAL POINT     APPOS280
C     NO. 2 DEPICTED IN FIGURE (10), REF 8                              APPOS290
C                                                                       APPOS300
      W2(IR)=(AR(IR)-BR(IR))-XCG(IR)                                    APPOS310
      U2(IR)=(((V1A(IR,1)+V2A(IR,1))*(TR(IR)-(0.1*TR(IR))))+            APPOS320
     1        (0.1*TR(IR)))-YPRL(IR)                                    APPOS330
C                                                                       APPOS340
C     ...CALCULATE ORDINATE (U4) AND ABCISSA (W4) OF CRITICAL POINT     APPOS350
C     NO. 4 DEPICTED IN FIGURE (10), REF 8                              APPOS360
C                                                                       APPOS370
      W4(IR)=W2(IR)                                                     APPOS380
      U4(IR)=((V1A(IR,1))*(TR(IR)-(0.1*TR(IR))))-YPRL(IR)               APPOS390
C                                                                       APPOS400
C     ...CALCULATE ORDINATE (U1) AND ABCISSA (W1) OF CRITICAL POINT     APPOS410
C     NO. 1 DEPICTED IN FIGURE (10), REF 8                              APPOS420
C                                                                       APPOS430
      W1(IR)=-((CR(IR)-AR(IR))+XCG(IR))                                 APPOS440
      YBK=(V1A(IR,10)+V2A(IR,10))*(TR(IR)-(0.1*TR(IR)))                 APPOS450
      YFC=(V1A(IR,10))*(TR(IR)-(0.1*TR(IR)))                            APPOS460
      IF(.NOT.(YCG(IR).GT.YBK))GO TO 40                                 APPOS470
          U1(IR)=YFC-YCG(IR)                                            APPOS480
      GO TO 45                                                          APPOS490
   40 CONTINUE                                                          APPOS500
      IF(.NOT.((YCG(IR).LE.YBK).AND.(YCG(IR).GE.YFC)))GO TO 44          APPOS510
          IF(.NOT.((ABS(YCG(IR)-YFC)).GT.(ABS(YBK-YCG(IR)))))           APPOS520
     1        GO TO 41                                                  APPOS530
              U1(IR)=YFC-YCG(IR)                                        APPOS540
          GO TO 43                                                      APPOS550
   41     CONTINUE                                                      APPOS560
          IF(.NOT.((ABS(YCG(IR)-YFC)).LT.(ABS(YBK-YCG(IR)))))           APPOS570
     1        GO TO 42                                                  APPOS580
              U1(IR)=YBK-YCG(IR)                                        APPOS590
          GO TO 43                                                      APPOS600
```

```
   42            CONTINUE                                                          APPOS610
                    U1(IR)=0.0                                                     APPOS620
   43            CONTINUE                                                          APPOS630
                 GO TO 45                                                          APPOS640
   44            CONTINUE                                                          APPOS650
                    U1(IR)=YBK-YCG(IR)                                             APPOS660
   45            CONTINUE                                                          APPOS670
C                                                                                  APPOS680
C           ...CALCULATE ORDINATE (U3) AND ABCISSA (W3) OF CRITICAL POINT          APPOS690
C           NO. 3 DEPICTED IN FIGURE (10), REF 8                                   APPOS700
C                                                                                  APPOS710
                 W3(IR)=CR(IR)-ABS(W1(IR))                                         APPOS720
                 YBK=(V1F(IR,11)+V2F(IR,11))*(TR(IR)-(0.1*TR(IR)))                 APPOS730
                 YFC=(V1F(IR,11))*(TR(IR)-(0.1*TR(IR)))                            APPOS740
                 IF(.NOT.(YCG(IR).GT.YBK))GO TO 46                                 APPOS750
                    U3(IR)=YFC-YCG(IR)                                             APPOS760
                 GO TO 51                                                          APPOS770
   46            CONTINUE                                                          APPOS780
                 IF(.NOT.((YCG(IR).LE.YBK).AND.(YCG(IR).GE.YFC)))GO TO 50          APPOS790
                    IF(.NOT.((ABS(YCG(IR)-YFC)).GT.(ABS(YBK-YCG(IR)))))            APPOS800
     1              GO TO 47                                                       APPOS810
                       U3(IR)=YFC-YCG(IR)                                          APPOS820
                    GO TO 49                                                       APPOS830
   47               CONTINUE                                                       APPOS840
                    IF(.NOT.((ABS(YCG(IR)-YFC)).LT.(ABS(YBK-YCG(IR)))))            APPOS850
     1              GO TO 48                                                       APPOS860
                       U3(IR)=YBK-YCG(IR)                                          APPOS870
                    GO TO 49                                                       APPOS880
   48               CONTINUE                                                       APPOS890
                       U3(IR)=0.0                                                  APPOS900
   49               CONTINUE                                                       APPOS910
                 GO TO 51                                                          APPOS920
   50            CONTINUE                                                          APPOS930
                    U3(IR)=YBK-YCG(IR)                                             APPOS940
   51            CONTINUE                                                          APPOS950
   52 CONTINUE                                                                     APPOS960
      RETURN                                                                       APPOS970
      END                                                                          APPOS980
```

```
      SUBROUTINE ELDVCL(VCLBLD)                                          APP1C010
C                                                                        APP1C020
CCC                                                                      APP1C030
CCC   SUBROUTINE:  BLDVOL                  DATE OF LAST REVISION: APR 63 APP1C040
CCC                                                                      APP1C050
CCC   INPUT              OUTPUT            DEFINITION                    APP1C060
CCC                                                                      APP1C070
CCC   DIA                                  PROPELLER DIAMETER (FEET)     APP1C080
CCC   Z                                    NO. OF PROPELLER BLADES       APP1C090
CCC   COMMON/AREBLD/                       BLADE SECTION AREAS (FEET**2) APP1C100
CCC                      VOLBLD            PROPELLER BLADE VOLUME        APP1C110
CCC                                        (FEET**3)                     APP1C120
C                                                                        APP1C130
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,               APP1C140
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,      APP1C150
     2       POWBAL,DIACNU,AEADCV,TCSTRS,                                APP1C160
     3       VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                APP1C170
     4       PWATVA,PROMAT,DIALIM,ETARR,                                 APP1C180
     5       RJ,C75R,R75R,KT,KQ                                          APP1C190
      REAL*4 AREA(10),WIDTH,VOL1,VOL2,VOLBLD                             APP1C200
      COMMON /GLOECM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL, APP1C210
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,      APP1C220
     2AEACCV,TCSTRS,RJ                                                   APP1C230
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,  APP1C240
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                               APP1C250
      COMMON /AREELD/AREA                                                APP1C260
C                                                                        APP1C270
CCC   DETERMINE BLADE VOLUME BY SIMPSON INTEGRATION SCHEME OF BLADE      APP1C280
CCC   CROSS-SECTIONAL AREAS FROM 2/10 RADIUS OUTWARD TO TIP              APP1C290
C                                                                        APP1C300
      VOL1=(((DIA/2.0)*0.1/3.0)*(AREA(2)+(4.0*AREA(3))+(2.0*AREA(4))+    APP1C310
     1                           (4.0*AREA(5))+(2.0*AREA(6))+            APP1C320
     2                           (4.0*AREA(7))+(2.0*AREA(8))+            APP1C330
     3                           (4.0*AREA(9))+AREA(10))                 APP1C340
C                                                                        APP1C350
CCC   DETERMINE BLADE VOLUME FROM 2/10 RADIUS INWARD TO R=.18R FOR 3 & 7 APP1C360
CCC   BLADE PROPELLERS OR R=.167R FOR 4,5,&6 BLADE PROPELLERS USING      APP1C370
CCC   SIMPLE TRAPEZOIDAL INTEGRATION SCHEME                              APP1C380
C                                                                        APP1C390
      IF(.NOT.(Z.EQ.3.0))GO TO 1                                         APP1C400
         WIDTH=(DIA/2.0)*(0.2-0.18)                                      APP1C410
      GO TO 5                                                            APP1C420
    1 CONTINUE                                                           APP1C430
      IF(.NOT.(Z.EQ.4.0))GO TO 2                                         APP1C440
         WIDTH=(DIA/2.0)*(0.2-0.167)                                     APP1C450
      GO TO 5                                                            APP1C460
    2 CONTINUE                                                           APP1C470
      IF(.NOT.(Z.EQ.5.0))GO TO 3                                         APP1C480
```

```
            WIDTH=(DIA/2.0)*(0.2-0.167)                                 APP1C490
      GO TO 5                                                           APP1C500
    3 CONTINUE                                                          APP1C510
      IF(.NOT.(Z.EQ.6.0))GO TO 4                                        APP1C520
            WIDTH=(DIA/2.0)*(0.2-0.167)                                 APP1C530
      GO TO 5                                                           APP1C540
    4 CONTINUE                                                          APP1C550
            WIDTH=(DIA/2.0)*(0.2-0.18)                                  APP1C560
    5 CONTINUE                                                          APP1C570
      VOL2=((AREA(1)+AREA(2))/2.0)*WIDTH                                APP1C580
C                                                                       APP1C590
C     CALCULATE PROPELLER BLADE VOLUME                                  APP1C600
C                                                                       APP1C610
      VOLBLD=VOL1+VOL2                                                  APP1C620
      RETURN                                                            APP1C630
      END                                                               APP1C640
```

```
      SUBROUTINE ELPOW1(KT,SOWBAL)                                          APP1C670
C                                                                           APP1C680
CCC                                                                         APP1C690
CCC   SUBROUTINE: BLPOW1                    DATE OF LAST REVISION: FEB 83   APP1C700
CCC                                                                         APP1C710
CCC   INPUT          OUTPUT                 DEFINITION                      APP1C720
CCC                                                                         APP1C730
CCC   PE                                    HULL EFFECTIVE HORSEPOWER(HP)   APP1C740
CCC   KT                                    THRUST COEFFICIENT              APP1C750
CCC   DIA                                   PROPELLER DIAMETER (FT)         APP1C760
CCC   N                                     PROPELLER REVOLUTION RATE(RPM   APP1C770
CCC   WATRO                                 WATER DENSITY (LBF-SEC2/FT4)    APP1C780
CCC   V                                     SHIP SPEED (FT/SEC)             APP1C790
CCC   WT                                    WAKE FRACTION                   APP1C800
CCC   TD                                    THRUST DEDUCTION                APP1C810
CCC   ETARR                                 RELATIVE ROTATIVE EFFICIENCY    APP1C820
CCC                 SOWBAL                  CONSTRAINT VARIABLE FOR PRO-    APP1C830
CCC                                         PELLER-DEVELOPED EFFECTIVE      APP1C840
CCC                                         HORSEPOWER CONSTRAINT           APP1C850
CC                                          (SOWBAL<0)                      APP1C860
C                                                                           APP1C870
      REAL*4 ETAO,WEIGHT,AEOVAO,DIA,N,PE,PDIVD,QS,TC75R,V,                  APP1C880
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,         APP1C890
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                APP1C900
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,                   APP1C910
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                   APP1C920
     5       KT,PEDEV,THRST,PT,SOWBAL                                       APP1C930
      COMMON /GLOBCM/ETAO,WEIGHT,AEOVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,    APP1C940
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,        APP1C950
     2AEACCV,TCSTRS,RJ                                                      APP1C960
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA,     APP1C970
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                  APP1C980
C                                                                           APP1C990
CC    CALCULATE THRUST DEVELOPED BY EACH PROPELLER                          APP11000
C                                                                           APP11010
      THRST=(KT*WATRO*(DIA**4)*((N/60.0)**2))                               APP11020
C                                                                           APP11030
CC    DETERMINE HULL EFFECTIVE POWER DEVELOPED BY PROPELLER(S)              APP11040
C                                                                           APP11050
      PT=(THRST*((1.0-WT)*V))/550.0                                         APP11060
      PEDEV=((((1.0-TC)/(1.0-WT))*ETARR*PT)*NCSCRW)                         APP11070
C                                                                           APP11080
CC    CALCULATE CONSTRAINT VARIABLE                                         APP11090
C                                                                           APP11100
      SOWBAL=1.0-(PEDEV/PE)                                                 APP11110
      RETURN                                                                APP11120
      END                                                                   APP11130
```

```
      SUBROUTINE BLPOW2(KQ,SOWBAL)                                      APP11160
                                                                        APP11170
C     SUBROUTINE: BLPOW2                    DATE OF LAST REVISION: FEB 83APP11180
C                                                                       APP11190
C     INPUT          OUTPUT                 DEFINITION                 APP11200
C                                                                       APP11210
C     QS                                    DELIVERED TORQUE (FT-LBF)  APP11220
C     KQ                                    TORQUE COEFFICIENT         APP11230
C     DIA                                   PROPELLER DIAMETER (FT)    APP11240
C     N                                     PROPELLER REVOLUTION RATE(RPMAPP11250
C     WATRO                                 WATER DENSITY (LBF-SEC2/FT4)APP11260
C                    SOWBAL                 CONSTRAINT VARIABLE FOR PRO-APP11270
C                                           PELLER REQUIRED TORQUE     APP11280
C                                           (SOWBAL<0)                 APP11290
C                                                                       APP11300
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,              APP11310
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP11320
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,                               APP11330
     3       VK,TD,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,               APP11340
     4       PWATVA,PROMAT,DIALIM,ETARR,                                APP11350
     5       KQ,QSABD,SOWBAL                                            APP11360
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP11370
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,    APP11380
     2AEAOCV,TCSTRS,RJ                                                  APP11390
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA, APP11400
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP11410
C                                                                       APP11420
C     CALCULATE THE TORQUE ABSORBED BY PROPELLER                        APP11430
C                                                                       APP11440
      QSABD=(KQ*WATRO*(DIA**5)*((N/60.0)**2))                           APP11450
C                                                                       APP11460
C     CALCULATE CONSTRAINT VARIABLE                                     APP11470
C                                                                       APP11480
      SOWBAL=1.0-(QSABD/QS)                                             APP11490
      RETURN                                                            APP11500
      END                                                               APP11510
```

```
      SUBROUTINE ELPCW3(KT,KQ,SOWBLP,SOWBLQ)                                  APP11540
                                                                              APP11550
C                                                                             APP11560
C     SUBROUTINE: BLPCW3                    DATE OF LAST REVISION: FEB 83     APP11570
C                                                                             APP11580
C     INPLT          OUTPUT                 DEFINITION                       APP11590
C                                                                             APP11600
C     KT                                    THRUST COEFFICIENT               APP11610
C     KQ                                    TORQUE COEFFICIENT               APP11620
C     PE                                    HULL EFFECTIVE HORSEPOWER(HP)    APP11630
C     N                                     PROPELLER REVOLUTION RATE(RPM    APP11640
C     QS                                    DELIVERED TORQUE (FT-LBF)        APP11650
C     NOSCRW                                NUMBER OF PROPELLERS             APP11660
C     WT                                    WAKE FRACTION                    APP11670
C     TD                                    THRUST DEDUCTION                 APP11680
C     ETARR                                 RELATIVE ROTATIVE EFFICIENCY     APP11690
C                    SOWBLP                 CONSTRAINT VARIABLE FOR          APP11700
C                                           EFFECTIVE HORSEPOWER             APP11710
C                                           CONSTRAINT (SOWBLP<0)            APP11720
C                    SOWBLQ                 CONSTRAINT VARIABLE FOR          APP11730
C                                           DELIVERED POWER                  APP11740
C                                           CONSTRAINT (SOWBLQ<0)            APP11750
C                                                                             APP11760
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,                    APP11770
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,           APP11780
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                  APP11790
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                     APP11800
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,KT,KQ,               APP11810
     5       PII,ETAOSP,THRST,PEDEV,QPABD,PDABD,PC,SOWBLP,SOWBLQ              APP11820
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,      APP11830
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,          APP11840
     2AEAOCV,TCSTRS,RJ                                                        APP11850
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,       APP11860
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                    APP11870
      PII=3.141592654                                                         APP11880
C                                                                             APP11890
C     CALCULATE THRUST DEVELOPED BY EACH PROPELLER                            APP11900
C                                                                             APP11910
      THRST=(KT*WATRO*(DIA**4)*((N/60.0)**2))                                 APP11920
C                                                                             APP11930
C     DETERMINE  EFFECTIVE POWER DEVELOPED BY PROPELLER(S)                    APP11940
C                                                                             APP11950
      PT=(THRST*((1.0-WT)*V))/550.0                                           APP11960
      PEDEV=((((1.0-TD)/(1.0-WT))*ETARR*PT)*NOSCRW)                           APP11970
C                                                                             APP11980
C     CALCULATE THE TORQUE ABSORBED BY PROPELLER                              APP11990
C                                                                             APP12000
      QPABD=(KQ*WATRO*(DIA**5)*((N/60.0)**2))                                 APP12010
```

```
C
C     CALCULATE THE POWER ABSORBED BY THE PROPELLER                    APP12020
C                                                                      APP12030
      PDABD=(2.0*PII*CPABD*NI)/33000.0                                 APP12040
C                                                                      APP12050
C     CALCULATE THE POWER DELIVERED TO THE PROPELLER                   APP12060
C                                                                      APP12070
      PD=(2.0*PII*QS*NI)/33000.0                                       APP12080
C                                                                      APP12090
C     DETERMINE CONSTRAINT VARIABLES                                   APP12100
C                                                                      APP12110
      SOWBLP=1.0-(PEDEV/PE)                                            APP12120
      SOWBLC=(PDABD/PD)-1.0                                            APP12130
      RETURN                                                           APP12140
      END                                                              APP12150
                                                                       APP12160
```

```
      SUBROUTINE CALCKQ(J,PDIVD,AEDVAC,Z,REYAC,KQ)                          APP12190
                                                                            APP12200
C     SUBROUTINE: CALCKQ                    DATE OF LAST REVISION: FEB 83   APP12210
C                                                                           APP12220
C     INPUT           OUTPUT                DEFINITION                      APP12230
C                                                                           APP12240
C     AEDVAD                                EXPANDED AREA RATIO             APP12250
C     PDIVD                                 PITCH-DIAMETER RATIO            APP12260
C     Z                                     NO. OF BLADES                   APP12270
C     J                                     ADVANCE RATIO                   APP12280
C     REYNO                                 REYNOLD'S NO. 3/4 RADIUS        APP12290
C                                           (CORRECTED FOR T/C 3/4 RADIUS   APP12300
C                     KQ                    THRUST COEFFICIENT              APP12310
C                                                                           APP12320
      REAL*4 J,PDIVD,AEDVAD,Z,REYNO,KQ,KQ1,KQ2,KQ3,KQ4,KQ5,KQ6,KQ7,KQ8,     APP12330
     1       KQ9,KQ10,DELKQ,DELKQ1,DELKQ2,DELKQ3,REYFAC                     APP12340
C                                                                           APP12350
C     FIRST, CALCULATING "KQ1" THRU "KQ10".....                             APP12360
C                                                                           APP12370
      KQ1=(.0[illegible]79368)+((.00886523)*(J**2))+((-.032241)*J*PDIVD)+   APP12380
     1    ((.0034478)*(PDIVD**2))+((-.040[illegible]8811)*PDIVD*AEDVAD)     APP12390
      KQ2=((-.108[illegible]09)*J*PDIVD*AEDVAD)+((-.0885381)*(J**2)*PDIVD*AEDVAC)+APP12400
     1    ((.188561)*(PDIVD**2)*AEDVAD)+((-.0[illegible]370E71)*J*Z)+       APP12410
     2    ((.0051[illegible]696)*PDIVD*Z)                                   APP12420
      KQ3=((.02[illegible]9449)*J*PDIVD*Z)+((.00474[illegible]19)*(J**2)*PDIVD*Z)+APP12430
     1    ((-.00723408)*(J**2)*AEDVAD*Z)+((.00438388)*J*PDIVD*AEDVAD*Z)+    APP12440
     2    ((-.026[illegible]403)*(PDIVD**2)*AEDVAD*Z)                       APP12450
      KQ4=((.0558[illegible]82)*(J**3)*AEDVAD)+((.0161886)*(PDIVD**3)*AEDVAD)+APP12460
     1    ((.0031E086)*J*(PDIVD**3)*AEDVAC)+((.015896)*(AEDVAD**2))+        APP12470
     2    ((.471[illegible]29)*J*(AEDVAD**2))                               APP12480
      KQ5=((.[illegible]196283)*(J**3)*(AEDVAD**2))+((-.0502782)*PDIVD*     APP12490
     1    (AEDVAC**2))+((-.030055)*(J**3)*PDIVD*(AEDVAD**2))+               APP12500
     2    ((.0417122)*(J**2)*(PDIVD**2)*(AEDVAD**2))+                       APP12510
     3    ((-.039[illegible]722)*(PDIVD**3)*(AEDVAD**2))                    APP12520
      KQ6=((-.[illegible]C350024)*(PDIVD**6)*(AEDVAC**2))+((-.0106854)*(J**3)*Z)+APP12530
     1    ((.0011[illegible]903)*(J**3)*(PDIVD**3)*Z)+((-.0[illegible]0313912)*(PDIVD**6)*APP12540
     2    Z)+((.[illegible]035585)*(J**3)*AEDVAD*Z)                         APP12550
      KQ7=((-.[illegible]0142121)*(PDIVD**6)*AEDVAD*Z)+((-.0038363[illegible])*J*APP12560
     1    (AEDVAC**2)*Z)+((.0126803)*(PDIVD**2)*(AEDVAD**2)*Z)+             APP12570
     2    ((-.[illegible]0318278)*(J**2)*(PDIVD**3)*(AEDVAD**2)*Z)+         APP12580
     3    ((.0[illegible]334268)*(PDIVD**6)*(AEDVAC**2)*Z)                  APP12590
      KQ8=((-.001E3491)*J*PDIVD*(Z**2))+((.000112451)*(J**3)*(PDIVD**2)     APP12600
     1    *(Z**2))+((-.[illegible]0002[illegible]7228)*(J**3)*(PDIVD**6)*(Z**2))+APP12610
     2    ((.[illegible]0026[illegible]9551)*J*AEDVAD*(Z**2))+((.0[illegible]0083265)*(J**2)*AEDVAD*APP12620
     3    (Z**2))                                                           APP12630
      KQ9=((.[illegible]0015[illegible]334)*(PDIVD**2)*AEDVAD*(Z**2))+((.000302683)*APP12640
     1    (PDIVD**6)*AEDVAD*(Z**2))+((-.0001E43)*(AEDVAD**2)*(Z**2))+       APP12650
     2    ((-.[illegible]0004253[illegible]9)*(PDIVD**3)*(AEDVAC**2)*(Z**2))+APP12660
```

```
     3    ((.CCCCE69243)*(J**3)*(PDIVD**3)*(AEDVAC**2)*(Z**2))                    APP12670
      KQ10=((-.00C4655)*(PDIVD**6)*(AEDVAC**2)*(Z**2))+                          APP12680
     1     ((.000C554194)*J*(PDIVD**6)*(AEDVAC**2)*(Z**2))                      APP12690
C                                                                                APP12700
CC    NEXT,CALCULATE LOGARITHMIC REYNOLDS NUMBER FACTOR "REYFAC"                 APP12710
C                                                                                APP12720
C     WRITE(6,*)REYNO,REYAO,REYNO                                                APP12730
      REYFAC=ALOG10(REYNO)-0.301                                                 APP12740
C                                                                                APP12750
CC    THEN,CALCULATE "DELKQ=DELKQ1+DELKQ2+DELKQ3"......                          APP12760
C                                                                                APP12770
      DELKQ1=(-.0C0591412)+((.0006968S8)*PDIVD)+                                 APP12780
     1       ((-.C000666654)*Z*(PDIVD**6))+((.016C818)*(AEDVAC**2))              APP12790
      DELKQ2=((-.C0053805 1)*REYFAC*PDIVD)+((-.000595953)*REYFAC*                APP12800
     1       (PDIVD**2))+((.0000782099)*(REYFAC**2)*(PDIVD**2))+                 APP12810
     2       ((.0C000521 5S)*REYFAC*Z*AEDVAC*(J**2))                             APP12820
      DELKQ3=((-.C0000088528)*(REYFAC**2)*Z*AEDVAC*PDIVD*J)+                     APP12830
     1       ((.0C0023017 1)*REYFAC*Z*(PDIVD**6))+((-.0000018434 1)*             APP12840
     2       (REYFAC**2)*Z*(PDIVD**6))+((-.0C400252)*REYFAC*                     APP12850
     3       (AEDVAC**2))+((.000220915)*(REYFAC**2)*(AEDVAC**2))                 APP12860
      DELKQ=DELKQ1+DELKQ2+DELKQ3                                                 APP12870
C                                                                                APP12880
CC    FINALLY,CALCULATE THRUST COEFFICIENT "KC" WHERE                            APP12890
CC    "KQ=KQ1+KQ2+KQ3+KQ4+KQ5+KQ6+KQ7+KQ8+KQ9+KQ1C+DELKQ"                        APP12900
C                                                                                APP12910
      KQ=KQ1+KQ2+KQ3+KQ4+KQ5+KQ6+KQ7+KQ8+KQ9+KQ10+DELKQ                         APP12920
      RETURN                                                                     APP12930
      END                                                                        APP12940
```

```
      SUBROUTINE CALCKT(J,PDIVD,AEDVAC,Z,REYNC,KT)                          APP12670
C                                                                           APP12680
C     SUBROUTINE: CALCKT                    DATE OF LAST REVISION: FEB 83   APP12690
C                                                                           APP13000
C     INPUT          OUTPUT                 DEFINITION                     APP13010
C                                                                           APP13020
C     AEDVAC                                EXPANDED AREA RATIO            APP13030
C     PDIVD                                 PITCH-DIAMETER RATIO           APP13040
C     Z                                     NO. OF BLADES                  APP13050
C     J                                     ADVANCE RATIO                  APP13060
C     REYNO                                 REYNOLDS NO. 3/4 RADIUS        APP13070
C                                           (CORRECTED FOR T/C 3/4 RADIUS  APP13080
C                    KT                   THRUST COEFFICIENT             APP13090
C                                                                           APP13100
      REAL*4 J,PDIVD,AEDVAC,Z,REYNO,KT,KT1,KT2,KT3,KT4,KT5,KT6,KT7,KT8,     APP13110
     1       DELKT,DELKT1,DELKT2,DELKT3,REYFAC                              APP13120
C                                                                           APP13130
C     FIRST, CALCULATING "KT1" THRU "KT8"......                             APP13140
C                                                                           APP13150
      KT1=.00666456+((-.204554)*J)+((.166351)*PDIVD)+                       APP13160
     1           ((.158114)*(PDIVD**2))+((-.147581)*(J**2)*AEDVAC)          APP13170
      KT2=((-.481497)*J*PDIVD*AEDVAC)+((.415437)*(PDIVD**2)*AEDVAC)+        APP13180
     1    ((.0144043)*Z)+((-.0530054)*(J**2)*Z)+((.0143481)*PDIVD*Z)        APP13190
      KT3=((.0606626)*J*PDIVD*Z)+((-.0125894)*AEDVAC*Z)+                    APP13200
     1    ((.0109689)*J*AEDVAC*Z)+((-.133698)*(PDIVD**3))+((.00638407)*     APP13210
     2    (PDIVD**6))                                                       APP13220
      KT4=((-.00132716)*(J**2)*(PDIVD**6))+((.168496)*(J**3)*AEDVAC)+       APP13230
     1    ((-.0507214)*(AEDVAC**2))+((.0854559)*(J**2)*(AEDVAC**2))+        APP13240
     2    ((-.0504475)*(J**3)*(AEDVAC**2))                                  APP13250
      KT5=((.0104651)*J*(PDIVD**6)*(AEDVAC**2))+((-.00648272)*(J**2)*       APP13260
     1    (PDIVD**6)*(AEDVAC**2))+((-.00841728)*(PDIVD**3)*Z)+              APP13270
     2    ((.0166424)*J*(PDIVD**3)*Z)+((-.00102296)*(J**3)*(PDIVD**3)*Z)    APP13280
      KT6=((-.0311791)*(PDIVD**3)*AEDVAC*Z)+((.0166041)*J*(AEDVAC**2)*Z)+   APP13290
     1    ((-.00410798)*(PDIVD**2)*(AEDVAC**2)*Z)+((-.000606848)*(Z**2))    APP13300
     2   +((-.0049815)*J*(Z**2))                                            APP13310
      KT7=((.0025983)*(J**2)*(Z**2))+((-.000560526)*(J**3)*(Z**2))+         APP13320
     1    ((-.00163652)*J*(PDIVD**2)*(Z**2))+((-.000328787)*J*              APP13330
     2    (PDIVD**6)*(Z**2))+((.000116502)*(J**2)*(PDIVD**6)*(Z**2))        APP13340
      KT8=((.0006904)*AEDVAC*(Z**2))+((.00421745)*(PDIVD**3)*AEDVAC*        APP13350
     1    (Z**2))+((.000056529)*(J**3)*(PDIVD**6)*AEDVAC*(Z**2))+           APP13360
     2    ((-.0014656)*(PDIVD**3)*(AEDVAC**2)*(Z**2))                       APP13370
C                                                                           APP13380
C     NEXT,CALCULATE LOGARITHMIC REYNOLDS NUMBER FACTOR "REYFAC"            APP13390
C                                                                           APP13400
C     WRITE(6,*)REYNC,REYNO                                                 APP13410
      REYFAC=ALOG10(REYNO)-0.301                                            APP13420
C                                                                           APP13430
C     THEN,CALCULATE "DELKT=DELKT1+DELKT2+DELKT3"......                     APP13440
```

```
C
      DELKT1=(.00C353485)+((-.00333758)*AEDVAC*(J**2))+                 APP13450
     1       ((-.C047E125)*AEDVAO*PDIVD*J)                              APP13460
      DELKT2=((.0C0257792)*(REYFAC**2)*AECVAO*(J**2))+                  APP13470
     1       ((.0C006431S2)*REYFAC*(PDIVD**6)*(J**2))+                  APP13480
     2       ((-.C000110636)*(REYFAC**2)*(PDIVD**6)*(J**2))             APP13490
      DELKT3=((-.C000276305)*(REYFAC**2)*Z*AECVAO*(J**2))+              APP13500
     1       ((.0C009S4)*REYFAC*Z*AEDVAO*PDIVD*J)+                      APP13510
     2       ((.0C000320S9)*REYFAC*(Z**2)*AEDVAO*(PDIVD**3)*J)          APP13520
      DELKT=DELKT1+DELKT2+DELKT3                                        APP13530
C                                                                       APP13540
CC    FINALLY,CALCULATE THRUST COEFFICIENT "KT" WHERE                   APP13550
CC    "KT=KT1+KT2+KT3+KT4+KT5+KT6+KT7+KT8+DELKT".....                   APP13560
C                                                                       APP13570
      KT=KT1+KT2+KT3+KT4+KT5+KT6+KT7+KT8+DELKT                          APP13580
      RETURN                                                            APP13590
      END                                                               APP13600
                                                                        APP13610
```

```
      SUBROUTINE CALCQS(KQ,SQS)                                          APP13640
                                                                         APP13650
C     SUBROUTINE: CALCQS                    DATE OF LAST REVISION: FEB 83APP13660
C                                                                        APP13670
C     INPUT           OUTPUT                DEFINITION                 APP13680
C                                                                        APP13690
C     KQ                                    TORQUE COEFFICIENT         APP13700
C     DIA                                   PROPELLER DIAMETER (FT)    APP13710
C     N                                     PROPELLER REVOLUTION RATE(RPMAPP13720
C     WATRO                                 WATER DENSITY (LBF-SEC2/FT4) APP13730
C                     SQS                   DELIVERED TORQUE (FT-LBF)  APP13740
C                                                                        APP13750
      REAL*4 ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,               APP13760
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,      APP13770
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                             APP13780
     3       VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                APP13790
     4       PWATVA,PROMAT,DIALIM,ETARR,AEADMN,TC75MN,SC,                APP13800
     5       KQ,SQS                                                      APP13810
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP13820
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,     APP13830
     2AEAOCV,TCSTRS,RJ                                                   APP13840
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,  APP13850
     1PROMAT,DIALIM,ETARR,AEADMN,TC75MN,SC                               APP13860
                                                                         APP13870
C     CALCULATE DELIVERED TORQUE REQUIRED BY PROPELLER                   APP13880
C                                                                        APP13890
      SQS=(KQ*WATRO*(DIA**5)*((N/60.0)**2))                              APP13900
      RETURN                                                             APP13910
      END                                                                APP13920
```

```
      SUBROUTINE CALCPE(KT,SPE)                                          APP13550
C                                                                        APP13560
CCC   SUBROUTINE: CALCPE                    DATE OF LAST REVISION: FEB 83APP13570
CCC                                                                      APP13980
CCC   INPUT           OUTPUT                DEFINITION                   APP13590
CCC                                                                      APP14000
CCC   KT                                    THRUST COEFFICIENT           APP14010
CCC   DIA                                   PROPELLER DIAMETER (FT)      APP14020
CCC   N                                     PROPELLER REVOLUTION RATE(RPMAPP14030
CCC   WATRO                                 WATER DENSITY (LBF-SEC2/FT4) APP14040
CCC   TD                                    THRUST DEDUCTION             APP14050
CCC   WT                                    TAYLOR WAKE FRACTION         APP14060
CCC   V                                     VELOCITY (FT/SEC)            APP14070
CCC                   SPE                   EFFECTIVE POWER (HP)         APP14080
C                                                                        APP14090
      REAL*4  ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,              APP14100
     1        RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP14110
     2        POWBAL,DIACNU,AEAOCV,TCSTFS,RJ,                            APP14120
     3        VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,               APP14130
     4        PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP14140
     5        KT,SPE,T                                                   APP14150
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP14160
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,     APP14170
     2AEAOCV,TCSTFS,RJ                                                  APP14180
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,  APP14190
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP14200
C                                                                        APP14210
CCC   CALCULATE THRUST DEVELOPED BY PROPELLER                            APP14220
C                                                                        APP14230
      T=(KT*WATRO*(DIA**4)*((N/60.0)**2))                                APP14240
C                                                                        APP14250
CCC   CALCULATE EFFECTIVE HORSEPOWER DEVELOPED BY PROPELLER              APP14260
C                                                                        APP14270
      SPE=((1.0-TC)/(1.0-WT))*((T*(1.0-WT)*V)/550.0)                     APP14280
      RETURN                                                             APP14290
      END                                                                APP14300
```

```
      SUBROUTINE CAVCNA(KT,SEAOCV)                                          APP14330
                                                                            APP14340
C     SUBROUTINE: CAVCNA                  DATE OF LAST REVISION: FEB 85     APP14350
C                                                                           APP14360
C     INPUT          OUTPUT               DEFINITION                        APP14370
C                                                                           APP14380
C     PATM                                ATMOSPHERIC PRESSURE (PSIA)       APP14390
C     WATRO                               WATER DENSITY (LBF-SEC2/FT4)      APP14400
C     PWATVA                              VAPORIZATION PRESSURE FOR WATER   APP14410
C                                         (PSIA)                            APP14420
C     HCL                                 DEPTH OF PROPELLER SHAFT          APP14430
C                                         CENTERLINE (FT)                   APP14440
C     KT                                  THRUST COEFFICIENT                APP14450
C     DIA                                 PROPELLER DIAMETER (FT)           APP14460
C     N                                   PROPELLER REVOLUTION RATE(RPM)    APP14470
C     Z                                   NO. OF BLADES                     APP14480
C     NOSCRW                              NO. OF PROPELLERS                 APP14490
C     AEOVAO                              PROPELLER EXPANDED AREA RATIO     APP14500
C                       SEAOCV            CONSTRAINT VARIABLE FOR PRO-      APP14510
C                                         PELLER EXPANDED AREA RATIO        APP14520
C                                         CONSTRAINT (SEAOCV<0)             APP14530
C                                                                           APP14540
      REAL*4 ETAO,WEIGHT,AEOVAO,DIA,N,PE,FOIVD,QS,TC75R,V,                  APP14550
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,         APP14560
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ                                 APP14570
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                   APP14580
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                   APP14590
     5       KT,PCMNPV,THRST,SEACMN,SEAOCV                                  APP14600
      COMMON /GLOBCM/ETAO,WEIGHT,AEOVAO,DIA,N,PE,FOIVD,QS,TC75R,V,RJCNL,    APP14610
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,        APP14620
     2AEACCV,TCSTRS,RJ                                                      APP14630
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,     APP14640
     1PROMAT,DIALIM,ETARR,AEACMN,TC75MN,SC                                  APP14650
C                                                                           APP14660
C     CALCULATE DIFFERENCE BETWEEN STATIC PRESSURE AT SHAFT CENTERLINE      APP14670
C     & WATER VAPORIZATION PRESSURE                                         APP14680
C                                                                           APP14690
      POWAPV=(PATM*144.0)+(WATRO*32.174*HCL)-(PWATVA*144.0)                 APP14700
C                                                                           APP14710
C     DETERMINE MINIMUM REQUIRED EXPANDED AREA RATIO FOR PROPELLER(S)       APP14720
C     USING "KELLER" CRITERIA FROM RELATION (13), REF 2                     APP14730
C                                                                           APP14740
      THRST=(KT*WATRO*(DIA**4)*((N/60.0)**2))                               APP14750
      SEACMN=((1.3+(0.3*Z))*THRST)/((DIA**2)*POWAPV)                        APP14760
C                                                                           APP14770
C     CORRECT ACCORDING TO NUMBER OF PROPELLERS                             APP14780
C                                                                           APP14790
      IF(.NOT.(NOSCRW.EQ.1.0))GO TO 1                                       APP14800
```

```
      SEACMN=SEACMN+0.2                                                 APP14810
      GO TO 3                                                           APP14820
    1 CONTINUE                                                          APP14830
      IF(.NOT.(NOSCRW.EQ.2.0))GO TO 2                                   APP14840
      SEACMN=SEACMN+0.1                                                 APP14850
      GO TO 3                                                           APP14860
    2 CONTINUE                                                          APP14870
      SEACMN=SEACMN+0.0                                                 APP14880
    3 CONTINUE                                                          APP14890
      AEACMN=SEAOMN                                                     APP14900
C                                                                       APP14910
CC    DETERMINE CONSTRAINT VARIABLE                                     APP14920
C                                                                       APP14930
      SEAOCV=(SEACMN/AEDVAO)-1.0                                        APP14940
      RETURN                                                            APP14950
      END                                                               APP14960
```

```
      SUBROUTINE CH75RA(C75R)                                                  APP14590
C                                                                              APP15000
C     SUBROUTINE:  CH75RA                    DATE OF LAST REVISION: Feb 83     APP15010
C                                                                              APP15020
C     INPUT              OUTPUT              DEFINITION                        APP15030
C                                                                              APP15040
C     AEDVAD                                 EXPANED AREA RATIO                APP15050
C     DIA                                    PROPELLER DIAMETER  (FEET)        APP15060
C     Z                                      NO. OF BLADES                     APP15070
C                        C75R                CHORD LENGTH AT 3/4 RADIUS        APP15080
C                                            (FEET)                            APP15090
      REAL*4 ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,                     APP15100
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEACCU,TC75CL,TC75CU,            APP15110
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                   APP15120
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                      APP15130
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                      APP15140
     5       C75R                                                              APP15150
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,       APP15160
     1RJCNU,R75RCL,R75RCU,AEACCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,           APP15170
     2AEACCV,TCSTRS,RJ                                                         APP15180
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNL,TEMP,NOSCRW,HCL,PATM,PWATVA,        APP15190
     1PROMAT,DIALIM,ETARR,AEACMN,TC75MN,SC                                     APP15200
C                                                                              APP15210
C     CALCULATE CHORD LENGTH AT 3/4 RADIUS USING RELATION (17),REF 2           APP15220
C                                                                              APP15230
      C75R=(2.073*AEDVAO*DIA)/Z                                                APP15240
      RETURN                                                                   APP15250
      END                                                                      APP15260
                                                                               APP15270
```

```
      SUBROUTINE CNFGLD                                                 APP15300
                                                                        APP15310
C     SUBROUTINE: CNFGLD                DATE OF LAST REVISION: APR 83   APP15320
                                                                        APP15330
C     INPUT             OUTPUT          DEFINITION                      APP15340
                                                                        APP15350
C     DIA                               PROPELLER DIAMETER (FT)         APP15360
C     N                                 PROPELLER REVOLUTION RATE (RPM) APP15370
C     PDIVD                             PITCH-DIAMETER RATIO            APP15380
C     Z                                 NO. OF PROPELLER BLADES         APP15390
C     PROMAT                            PROPELLER MATERIAL IDENTIFIER   APP15400
C                                           1: CAST IRON                APP15410
C                                           2: CAST STEEL               APP15420
C                                           3: TYPE 2 BRONZE            APP15430
C                                           4: TYPE 4 NI-AL BRONZE      APP15440
C                                           5: STAINLESS STEEL          APP15450
C     COMMON /AREELD/                   BLADE SECTION AREAS (FEET**2)   APP15460
C     COMMON /CGX/                      LOCATION OF BLADE CROSS-SEC-    APP15470
C                                       TIONAL AREA CENTROID WITH       APP15480
C                                       RESPECT TO GENERATOR LINE       APP15490
C                                       (FEET)                          APP15500
C     COMMON /CGY/                      LOCATION OF BLADE CROSS-SEC-    APP15510
C                                       TIONAL AREA CENTROID WITH       APP15520
C                                       RESPECT TO PITCH-REFERENCE      APP15530
C                                       LINE (FEET)                     APP15540
C                       COMMON /CFGFD/  CENTRIFUGAL FORCE COMPONENTS,   APP15550
C                                       ALONG THE PROPELLER RADIUS,     APP15560
C                                       PARALLEL TO GENERATOR LINE,     APP15570
C                                       WHICH ACT ON A BLADE SECTION    APP15580
C                                       AT ITS NEUTRAL AXES ORIGIN      APP15590
C                                       (LBF)                           APP15600
C                       COMMON /CMCBN/  CENTIFUGAL BENDING MOMENT COM-  APP15610
C                                       PONENTS, ALONG THE PROPELLER    APP15620
C                                       RADIUS, PARALLEL TO THE PITCH   APP15630
C                                       REFERENCE (CHORD) LINE, WHICH   APP15640
C                                       ACT ON A BLADE SECTION AT ITS   APP15650
C                                       NEUTRAL AXES ORIGIN (FT-LBF)    APP15660
C                       COMMON /CMCBL/  CENTIFUGAL BENDING MOMENT COM-  APP15670
C                                       PONENTS, ALONG THE PROPELLER    APP15680
C                                       RADIUS, NORMAL TO THE PITCH     APP15690
C                                       REFERENCE (CHORD) LINE, WHICH   APP15700
C                                       ACT ON A BLADE SECTION AT ITS   APP15710
C                                       NEUTRAL AXES ORIGIN (FT-LBF)    APP15720
C                                                                       APP15730
      REAL*4  ETAO,WEIGHT,AEOVAO,DIA,N,PE,PDIVD,QS,TC75R,V,             APP15740
     1        RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEACCU,TC75CL,TC75CU,    APP15750
     2        FCWBAL,DIACNU,AEAOCV,TCSTRS,                              APP15760
     3        VK,TC,WT,Z,WATRC,WATNU,TEMP,NOSCRW,HCL,PATM,              APP15770
```

```
     4        FWATLA,PRCMAT,DIALIM,ETARR,                                    APP15780
     5        RJ,C75R,R75R,KT,KQ                                             APP15790
      REAL*4  AREA(10),XCG(10),YCG(10),RIXXNA(10),RIYYNA(10)                 APP15800
      REAL*4  SLMSW,SUMSVR,SUMSVT,SUMSVA                                     APP15810
      REAL*4  SMALLI(10),SMALLA(10),SMALLT(10),SMAIMA(10),                   APP15820
     1        SINBET(10),CCSBET(10),                                         APP15830
     2        SUM(10),SUMR(10),SUMT(10),SUMA(10),                            APP15840
     3        VCLO(10),XBRCGO(10),BIGTO(10),BIGAO(10),SMPO(10),SMQO(10)      APP15850
      REAL*4  CMCBN(10),CMCBL(10),BIGNO(10),RADIUS                           APP15860
      INTEGER*4 IF,IRPI,KOUNT,I                                              APP15870
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,US,TC75R,V,RJCNL,     APP15880
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,CIACNU,         APP15890
     2AEACCV,TCSTRS,RJ                                                       APP15900
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA,      APP15910
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                   APP15920
      COMMON /AREELD/AREA                                                    APP15930
      COMMON /CGX/XCG                                                        APP15940
      COMMON /CGY/YCG                                                        APP15950
      COMMON /A2MCMX/RIYYNA                                                  APP15960
      COMMON /A2MCMY/RIXXNA                                                  APP15970
      COMMON /CFGEMN/CMCBN                                                   APP15980
      COMMON /CFGEML/CMCBL                                                   APP15990
      COMMON /CFGFD/BIGNO                                                    APP16000
      PII=3.141592654                                                        APP16010
                                                                             APP16020
C     CALCULATE RAKE ANGLE IN RADIANS                                        APP16030
                                                                             APP16040
      ETA=15.0*(PII/180.0)                                                   APP16050
                                                                             APP16060
C     SPECIFY WEIGHT DENSITY OF MATERIAL SELECTED WHERE...                   APP16070
                                                                             APP16080
C     PRCMAT        MATERIAL              WEIGHT DENSITY (LBF/IN**3)         APP16090
C       1           CAST IRON               .260                           APP16100
C       2           CAST STEEL              .284                           APP16110
C       3           TYPE 2 BRONZE           .305                           APP16120
C       4           TYPE 4 NI-AL BRONZE     .278                           APP16130
C       5           STAINLESS STEEL         .283                           APP16140
C                                                                            APP16150
      IF(PRCMAT.EQ.1.0)WD=.260                                               APP16160
      IF(PRCMAT.EQ.2.0)WD=.284                                               APP16170
      IF(PRCMAT.EQ.3.0)WD=.305                                               APP16180
      IF(PRCMAT.EQ.4.0)WD=.278                                               APP16190
      IF(PRCMAT.EQ.5.0)WD=.283                                               APP16200
                                                                             APP16210
C     DETERMINE VALUES FOR...                                                APP16220
                                                                             APP16230
C     SMALLI(IR)        DISTANCE TO THE PITCH REFERENCE LINE, ALONG THE      APP16240
C                       PROPELLER RADIUS, WITH RESPECT TO A LINE NORMAL      APP16250
```

```
C                       TO THE PROPELLER SHAFT AXIS AND PASSING THROUGH   APP16260
C                       THE INTERSECTION OF THE GENERATOR LINE AND THE    APP16270
C                       PROPELLER SHAFT AXIS (FEET)                       APP16280
C     SMALLA(IR)        DISTANCE, PARALLEL TO THE PROPELLER SHAFT AXIS,    APP16290
C                       OF EACH BLADE SECTION NEUTRAL AXES ORIGIN, GIVEN  APP16300
C                       BY COORDINATES ( XCG(IR),YCG(IR) ), WITH RESPECT  APP16310
C                       TO THE INTERSECTION OF THE PITCH REFERENCE LINE   APP16320
C                       AND THE GENERATOR LINE (FEET)                     APP16330
C     SMALLT(IR)        DISTANCE, NORMAL TO THE PROPELLER SHAFT AXIS,      APP16340
C                       OF EACH BLADE SECTION NEUTRAL AXES ORIGIN, GIVEN  APP16350
C                       BY COORDINATES ( XCG(IR),YCG(IR) ), WITH RESPECT  APP16360
C                       TO THE INTERSECTION OF THE PITCH REFERENCE LINE   APP16370
C                       AND THE GENERATOR LINE (FEET)                     APP16380
C                                                                         APP16390
C     ... FOR EACH BLADE SECTION ALONG THE PROPELLER RADIUS               APP16400
C                                                                         APP16410
      DO 9 IR=2,10                                                        APP16420
      IF(.NOT.(Z.EQ.4.0))GO TO 7                                          APP16430
            IF(.NOT.(IR.EQ.2))GO TO 2                                     APP16440
                  RF=0.822                                                APP16450
            GO TO 6                                                       APP16460
    2       CONTINUE                                                      APP16470
            IF(.NOT.(IR.EQ.3))GO TO 3                                     APP16480
                  RF=0.887                                                APP16490
            GO TO 6                                                       APP16500
    3       CONTINUE                                                      APP16510
            IF(.NOT.(IR.EQ.4))GO TO 4                                     APP16520
                  RF=0.950                                                APP16530
            GO TO 6                                                       APP16540
    4       CONTINUE                                                      APP16550
            IF(.NOT.(IR.EQ.5))GO TO 5                                     APP16560
                  RF=0.992                                                APP16570
            GO TO 6                                                       APP16580
    5       CONTINUE                                                      APP16590
                  RF=1.00                                                 APP16600
    6       CONTINUE                                                      APP16610
            DENOM=SQRT(((RF*PDIVD)**2)+(PII**2))                          APP16620
            SINBET(IR)=(RF*PDIVD)/DENOM                                   APP16630
            COSBET(IR)=(PII)/DENOM                                        APP16640
      GO TO 8                                                             APP16650
    7 CONTINUE                                                            APP16660
            DENOM=SQRT((PDIVD**2)+(PII**2))                               APP16670
            SINBET(IR)=(PDIVD)/DENOM                                      APP16680
            COSBET(IR)=(PII)/DENOM                                        APP16690
    8 CONTINUE                                                            APP16700
      SMALLI(IR)=(DIA/2.0)*(FLOAT(IR)/10.0)*(TAN(ETA))                    APP16710
      SMALLA(IR)=(XCG(IR)*SINBET(IR))+(YCG(IR)*COSBET(IR))                APP16720
      SMALLT(IR)=(XCG(IR)*COSBET(IR))-(YCG(IR)*SINBET(IR))                APP16730
```

```
      SMAIMA(IR)=SMALLI(IR)-SMALLA(IR)                                  APP16740
    5 CONTINUE                                                          APP16750
C                                                                       APP16760
C     CALCULATE TABULAR SUMMATIONS FOR INTEGRATION ALONG THE PROPELLER  APP16770
C     RADIUS                                                            APP16780
C                                                                       APP16790
      DO 10 IR=2,5                                                      APP16800
      IRP1=IR+1                                                         APP16810
      SUM(IR)=AREA(IR)+AREA(IRP1)                                       APP16820
      SUMR(IR)=(FLOAT(IR)*AREA(IR))+(FLOAT(IRP1)*AREA(IRP1))            APP16830
      SUMT(IR)=(SMALLT(IR)*AREA(IR))+(SMALLT(IRP1)*AREA(IRP1))          APP16840
      SUMA(IR)=(SMAIMA(IR)*AREA(IR))+(SMAIMA(IRP1)*AREA(IRP1))          APP16850
   10 CONTINUE                                                          APP16860
C                                                                       APP16870
C     INTEGRATE ALONG THE PROPELLER RADIUS TO DETERMINE THE FORCE AND   APP16880
C     BENDING MOMENT COMPONENTS,ACTING ON A BLADE SECTION AT ITS NEUTRALAPP16890
C     AXES ORIGIN, WHICH ARE IMPOSED BY CENTRIFUGAL LOADING OF THE BLADEAPP16900
C     ELEMENT VOLUME ABOVE THE BLADE SECTION UNDER CONSIDERATION        APP16910
C                                                                       APP16920
      DO 12 IR=2,5                                                      APP16930
      KCUNT=IR                                                          APP16940
      SUMSV=0.0                                                         APP16950
      SUMSVR=0.0                                                        APP16960
      SUMSVT=0.0                                                        APP16970
      SUMSVA=0.0                                                        APP16980
      DO 11 I=KCUNT,5                                                   APP16990
      SUMSV=SUMSV+SUM(I)                                                APP17000
      SUMSVR=SUMSVR+SUMR(I)                                             APP17010
      SUMSVT=SUMSVT+SUMT(I)                                             APP17020
      SUMSVA=SUMSVA+SUMA(I)                                             APP17030
   11 CONTINUE                                                          APP17040
CC                                                                      APP17050
CC    DETERMINE BLADE ELEMENT VOLUME (FT**3) ABOVE THE BLADE            APP17060
CC    SECTION UNDER CONSIDERATION                                       APP17070
CC                                                                      APP17080
      VOLO(IR)=0.5*(DIA/2.0)*(0.1)*(SUMSV)                              APP17090
CC                                                                      APP17100
CC    DETERMINE RADIAL FRACTION OF THE BLADE ELEMENT VOLUME'S CG        APP17110
CC    WITH RESPECT TO THE PROPELLER SHAFT AXIS                          APP17120
CC                                                                      APP17130
      XBRCGO(IR)=(SUMSVR/SUMSV)/10.0                                    APP17140
CC                                                                      APP17150
CC    DETERMINE DISTANCE (FEET) FROM THE GENERATOR LINE, NORMAL TO      APP17160
CC    THE PROPELLER SHAFT AXIS, OF THE BLADE ELEMENT VOLUME'S CG        APP17170
CC    WITH RESPECT TO THE PROPELLER SHAFT AXIS                          APP17180
CC                                                                      APP17190
      BIGTO(IR)=(SUMSVT/SUMSV)                                          APP17200
CC                                                                      APP17210
```

```
CC          DETERMINE DISTANCE (FEET) FROM THE GENERATOR LINE, PARALLEL   APP17220
CC          TO THE PROPELLER SHAFT AXIS, OF THE BLADE ELEMENT VOLUME'S CGAPP17230
CC          WITH RESPECT TO THE PROPELLER SHAFT AXIS                      APP17240
CC                                                                        APP17250
            BIGAO(IR)=(SUMSVA/SUMSV)                                      APP17260
CC                                                                        APP17270
CC          DETERMINE DISTANCE (FEET) FROM THE GENERATOR LINE, NORMAL TO  APP17280
CC          THE PROPELLER SHAFT AXIS, OF THE BLADE ELEMENT VOLUME'S CG    APP17290
CC          WITH RESPECT TO THE BLADE SECTION UNDER CONSIDERATION         APP17300
CC                                                                        APP17310
            SMPO(IR)=((FLOAT(IR)/10.0)/XBRCGO(IR))*BIGTO(IR)              APP17320
CC                                                                        APP17330
CC          DETERMINE DISTANCE (FEET) FROM THE GENERATOR LINE, PARALLEL   APP17340
CC          TO THE PROPELLER SHAFT AXIS, OF THE BLADE ELEMENT VOLUME'S CGAPP17350
CC          WITH RESPECT TO THE BLADE SECTION UNDER CONSIDERATION         APP17360
CC                                                                        APP17370
            SMGO(IR)=BIGAO(IR)-(((DIA/2.0)*(FLOAT(IR)/10.0))*TAN(ETA))    APP17380
CC                                                                        APP17390
CC          CALCULATE FORCE AND BENDING MOMENT COMPONENTS WHERE...         APP17400
CC                                                                        APP17410
CC          BIGNO(IR)          CENTRIFUGAL FORCE ACTING AT BLADE SECTION  APP17420
CC                             NEUTRAL AXES ORIGIN                        APP17430
CC          CMCBN(IR)          BENDING MOMENT COMPONENT, IMPOSED BY CENTRI-APP17440
CC                             FUGAL LOADING, PARALLEL TO PITCH REFERENCE  APP17450
CC                             (CHORD) LINE OF A BLADE SECTION            APP17460
CC          CMCBL(IR)          BENDING MOMENT COMPONENT, IMPOSED BY CENTRI-APP17470
CC                             FUGAL LOADING, NORMAL TO PITCH REFERENCE    APP17480
CC                             (CHORD) LINE OF A BLADE SECTION            APP17490
CC                                                                        APP17500
            RADIUS=(FLOAT(IR)/10.0)*(DIA/2.0)                             APP17510
            BIGNO(IR)=((WD*1726.0*VOLO(IR)*((2.0*PII*(N/60.0))**2)*       APP17520
     1                 (DIA/2.0)*XBRCGO(IR))/32.174)*                     APP17530
     2                (RADIUS/(SQRT((RADIUS**2)+((SMPO(IR))**2))))       APP17540
            CMCBN(IR)=BIGNO(IR)*((SMPO(IR)*SINBET(IR))+                   APP17550
     1                           (SMGO(IR)*COSBET(IR))+YCG(IR))           APP17560
            CMCBL(IR)=BIGNO(IR)*(XCG(IR)+                                 APP17570
     1                ((SMGO(IR)*SINBET(IR))-(SMPO(IR)*COSBET(IR))))     APP17580
         12 CONTINUE                                                      APP17590
            RETURN                                                        APP17600
            END                                                           APP17610
```

```
      SUBROUTINE COEFSA(SJ,R75R,KT,KQ)                                  APP17640
C                                                                       APP17650
C     SUBROUTINE: COEFSA                    DATE OF LAST REVISION: FEB 63APP17660
C                                                                       APP17670
C     INPLT           OUTPUT                DEFINITION                  APP17680
C                                                                       APP17690
C     AEDVAD                                EXPANDED AREA RATIO         APP17700
C     PDIVD                                 PITCH-DIAMETER RATIO        APP17710
C     Z                                     NO. OF BLADES               APP17720
C     SJ                                    ADVANCE COEFFICIENT         APP17730
C     R75R                                  REYNOLD'S NO. 3/4 RADIUS    APP17740
C                                           (CORRECTED FOR T/C 3/4 RADIUSAPP17750
C                     KT                    THRUST COEFFICIENT          APP17760
C                     KQ                    TORQUE COEFFICIENT          APP17770
C                                                                       APP17780
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,              APP17790
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP17800
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                            APP17810
     3       VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,               APP17820
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP17830
     5       R75R,KT,KQ,SJ                                              APP17840
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP17850
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,    APP17860
     2AEACCV,TCSTRS,RJ                                                  APP17870
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA, APP17880
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP17890
C                                                                       APP17900
C     CALCULATE THRUST & TORQUE COEFFICIENTS USING THE WAGENINGEN SERIESAPP17910
C     POLYNOMIALS GIVEN IN TABLES (5) AND (6), REF 2                    APP17920
C                                                                       APP17930
      CALL CALCKT(SJ,PDIVD,AEDVAD,Z,R75R,KT)                            APP17940
      CALL CALCKQ(SJ,PDIVD,AEDVAD,Z,R75R,KQ)                            APP17950
      RETURN                                                            APP17960
      END                                                               APP17970
```

```
      SUBROUTINE DICNUA(SIACNU)                                          APP18000
C                                                                        APP18010
C     SUBROUTINE: DICNUA                    DATE OF LAST REVISION: FEB 83APP18020
C                                                                        APP18030
C     INPUT           OUTPUT                DEFINITION                 APP18040
C                                                                        APP18050
C     DIA                                   PROPELLER DIAMETER (FT)    APP18060
C     DIALIM                                MAXIMUM DIAMETER PERMITTED BYAPP18070
C                                           HULL'S AFTERBODY (FT)      APP18080
C                     SIACNU                CONSTRAINT VARIABLE (UPPER APP18090
C                                           BOUND) ON DIAMETER (DIACNU<0)APP18100
      REAL*4 ETAO,WEIGHT,AEDVAU,DIA,N,PE,FDIVD,QS,TC75R,V,               APP18110
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,      APP18120
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                             APP18130
     3       VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                APP18140
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                APP18150
     5       SIACNU                                                      APP18160
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAU,DIA,N,PE,FDIVD,QS,TC75R,V,RJCNL, APP18170
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,     APP18180
     2AEAOCV,TCSTRS,RJ                                                   APP18190
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,  APP18200
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                               APP18210
C                                                                        APP18220
C     DETERMINE CONSTRAINT VARIABLE OF PROPELLER DIAMETER'S UPPER BOUND  APP18230
C     CONSTRAINT                                                         APP18240
C                                                                        APP18250
      SIACNU=(DIA/DIALIM)-1.0                                            APP18260
      RETURN                                                             APP18270
      END                                                                APP18280
```

```
      SUBROUTINE EXTCCN(Z,AECVAO,TC75R,AEAOCL,AEACCU,TC75CL,TC75CU)      APP18310
C                                                                        APP18320
C     SUBROUTINE: EXTCCN                  DATE CF LAST REVISION: FEB 83  APP18330
C                                                                        APP18340
C     INPUT            OUTPUT             DEFINITION                     APP18350
C                                                                        APP18360
C     Z                                   NC. OF BLADES                  APP18370
C     AECVAO                              EXPANDED AREA RATIO            APP18380
C     TC75R                               BLADE THICKNESS-TO-CHORD RATIO APP18390
C                      AEAOCL             EXPANDED AREA RATIO CONSTRAINT APP18400
C                                         VARIABLE (LOWER BOUND)(AEAOCL<0)APP18410
C                      AEAOCU             EXPANDED AREA RATIO CONSTRAINT APP18420
C                                         VARIABLE (UPPER BOUND)(AEAOCU<0)APP18430
C                      TC75CL             BLADE THICKNESS-TO-CHORD RATIO APP18440
C                                         CONSTRAINT VARIABLE (LOWER BOUND)APP18450
C                                         (TC75CL<0)                     APP18460
C                      TC75CU             BLADE THICKNESS-TO-CHORD RATIO APP18470
C                                         CONSTRAINT VARIABLE (UPPER BOUND)APP18480
C                                         (TC75CL<0)                     APP18490
C                                                                        APP18500
      REAL*4 Z,AECVAO,TC75R,AEAOCL,AEAOCU,TC75CL,TC75CU,                 APP18510
     1       AEAOLO,AEAOUP,TC75LO,TC75UP                                 APP18520
C                                                                        APP18530
C     SET LIMITS CN EXPANDED AREA RATIO BASED ON NUMBER OF BLADES        APP18540
C                                                                        APP18550
      IF(.NOT.(Z.EQ.3.0))GO TO 1                                         APP18560
          AEACLO=0.35                                                    APP18570
          AEACUP=0.80                                                    APP18580
      GO TO 6                                                            APP18590
    1 CONTINUE                                                           APP18600
      IF(.NOT.(Z.EQ.4.0))GO TO 2                                         APP18610
          AEACLO=0.40                                                    APP18620
          AEACUP=1.00                                                    APP18630
      GO TO 6                                                            APP18640
    2 CONTINUE                                                           APP18650
      IF(.NOT.(Z.EQ.5.0))GO TO 3                                         APP18660
          AEACLO=0.45                                                    APP18670
          AEACUP=1.05                                                    APP18680
      GO TO 6                                                            APP18690
    3 CONTINUE                                                           APP18700
      IF(.NOT.(Z.EQ.6.0))GO TO 4                                         APP18710
          AEACLO=0.50                                                    APP18720
          AEACUP=0.80                                                    APP18730
      GO TO 6                                                            APP18740
    4 CONTINUE                                                           APP18750
      IF(.NOT.(Z.EQ.7.0))GO TO 5                                         APP18760
          AEACLO=0.55                                                    APP18770
          AEACUP=0.85                                                    APP18780
```

```
      GO TO 6                                                                   APP1E790
    5 CONTINUE                                                                  APP18600
          AEACLO=0.35                                                           APP1E610
          AEACUP=1.05                                                           APP18820
    6 CONTINUE                                                                  APP18830
C                                                                               APP18840
CC    DETERMINE CONSTRAINT VARIABLES FOR EXPANDED AREA RATIO CONSTRAINT         APP18850
C                                                                               APP18860
      AEACCL=AEAOLC-AEOVAC                                                      APP1E870
      AEACCU=AEOVAO-AEAOUP                                                      APP18880
C                                                                               APP1E890
CC    DETERMINE CONSTRAINT VARIABLES FOR BLADE THICKNESS-TO-CHORD RATIO         APP18900
CC    CONSTRAINT                                                                APP18910
C                                                                               APP1E920
      TC75LO=(0.5)*(((0.0185-0.00125*Z)*Z)/(2.073*AEAOUP))                      APP18930
      TC75UP=(4.0)*(((0.0185-0.00125*Z)*Z)/(2.073*AEAOLO))                      APP18940
      TC75CL=TC75LO-TC75R                                                       APP1E950
      TC75CU=TC75R-TC75UP                                                       APP18900
      RETURN                                                                    APP1E970
      END                                                                       APP18980
```

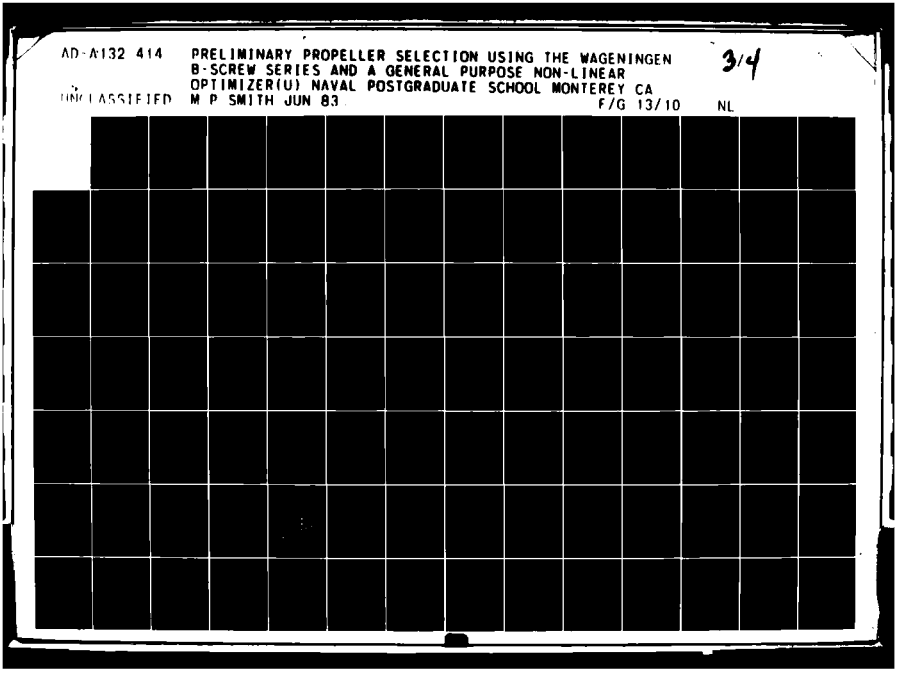
```
      SUBROUTINE HYDLD(KQ,KT)                                                  APP1$010
                                                                               APP1$020
C     SUBROUTINE: HYDLD                    DATE OF LAST REVISION: APR 83       APP1$030
                                                                               APP1$040
C     INPUT          OUTPUT                DEFINITION                        APP1$050
                                                                               APP1$060
C     DIA                                  PROPELLER DIAMETER (FT)           APP1$070
C     N                                    PROPELLER REVOLUTION RATE (RPM)   APP1$080
C     PDIVD                                PITCH-DIAMETER RATIO              APP1$090
C     KQ                                   TORQUE COEFFICIENT                APP1$100
C     KT                                   THRUST COEFFICIENT                APP1$110
C     WATRO                                WATER DENSITY (LBF-SEC2/FT4)      APP1$120
C     Z                                    NO. OF PROPELLER BLADES           APP1$130
C                    COMMON/HYDMOMN/       HYDRODYNAMIC MOMENTS PARALLEL     APP1$140
C                                          TO BLADE SECTION PITCH REFER-     APP1$150
C                                          ENCE (CHORD) LINE (FT-LBF)        APP1$160
C                    COMMON/HYDMOML/       HYDRODYNAMIC MOMENTS NORMAL       APP1$170
C                                          TO BLADE SECTION PITCH REFER-     APP1$180
C                                          ENCE (CHORD) LINE (FT-LBF)        APP1$190
                                                                               APP1$200
      REAL*4 ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,                     APP1$210
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,            APP1$220
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,                                      APP1$230
     3       VK,TD,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                      APP1$240
     4       PWATVA,PROMAT,DIALIM,ETARR,                                       APP1$250
     5       RJ,C75R,R75R,KT,KQ                                                APP1$260
      REAL*4 HMPN(10),HMPL(10),XO,PHI1(10),PHI2(10),GAM2(10),T,Q,              APP1$270
     1       EMT(10),BMQ(10),DENOM,RF,PII                                      APP1$280
      INTEGER*4 IR                                                             APP1$290
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,       APP1$300
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,           APP1$310
     2AEACCV,TCSTRS,RJ                                                         APP1$320
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNL,TEMP,NOSCRW,HCL,PATM,PWATVA,        APP1$330
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                     APP1$340
      COMMON /HYMCMN/HMPN                                                      APP1$350
      COMMON /HYMCML/HMPL                                                      APP1$360
      PII=3.141592654                                                          APP1$370
                                                                               APP1$380
C     DETERMINE VALUES ALONG THE PROPELLER RADIUS OF VARIOUS FUNCTIONS         APP1$390
C     OF XO AND XI DEFINED BY BRACKETED EXPRESSIONS IN RELATIONS (4),          APP1$400
C     (9) AND (19), REF 6                                                      APP1$410
                                                                               APP1$420
      DO 1 IR=2,10                                                             APP1$430
           XO=(FLOAT(IR))/10.0                                                 APP1$440
           PHI1(IR)=(1.0/15.0)*                                                APP1$450
     1             (8.0+(4.0*XO)+(3.0*(XO**2))-(15.0*(XO**3)))*                APP1$460
     2             (SQRT(1.0-XO))                                              APP1$470
           PHI2(IR)=(2.0/45.0)*                                                APP1$480
```

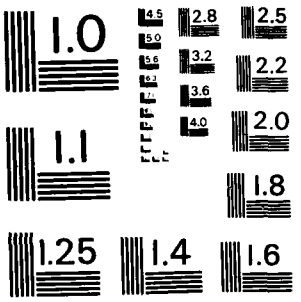
```
     1               (8.0-(8.0*X0)-(3.0*(X0**2))-(2.0*(X0**3))+          APP1$490
     2                (5.0*(X0**4)))*                                    APP1$500
     3               (SQRT(1.C-X0))                                      APP1$510
          GAP2(IR)=(2.0/15.0)*                                          APP1$520
     1               (4.0-(5.0*X0)-(2.0*(X0**2))+(3.0*(X0**3)))*        APP1$530
     2               (SQRT(1.C-X0))                                      APP1$540
    1 CONTINUE                                                          APP1$550
C                                                                       APP1$560
CC     CALCULATE THRUST DEVELOPED BY PROPELLER                          APP1$570
C                                                                       APP1$580
CC     T=(KT*RATRO*(DIA**4)*((N/60.0)**2))                              APP1$590
C                                                                       APP1$600
CC     CALCULATE TORQUE REQUIRED BY PROPELLER                           APP1$610
C                                                                       APP1$620
CC     Q=(KQ*RATRO*(DIA**5)*((N/60.0)**2))                              APP1$630
C                                                                       APP1$640
CC     CALCULATE BENDING MOMENTS DUE TO THRUST ( BMT(IR) ) AND TORQUE   APP1$650
CC     ( BMQ(IR) ) ALONG THE PROPELLER RADIUS USING RELATIONS (10) AND  APP1$660
CC     (26) RESPECTIVELY, REF 8                                         APP1$670
C                                                                       APP1$680
      DO 2 IR=2,10                                                      APP1$690
          BMT(IR)=((T*(DIA/2.0))/Z)*(PHI2(IR)/PHI1(2))                  APP1$700
          BMQ(IR)=(Q/Z)*(GAP2(IR)/PHI1(2))                              APP1$710
    2 CONTINUE                                                          APP1$720
C                                                                       APP1$730
CC     RESOLVE CALCULATED BENDING MOMENTS INTO COMPONENTS NORMAL AND    APP1$740
CC     PARALLEL TO PITCH REFERENCE (CHORD) LINE FOR EACH BLADE SECTION  APP1$750
CC     ALONG THE PROPELLER RADIUS USING RELATIONS (42) AND (43), REF 8  APP1$760
CC     REMEMBER TO ACCOUNT FOR PITCH REDUCTION OF FOUR BLADE (Z=4.0)    APP1$770
CC     PROPELLERS                                                       APP1$780
C                                                                       APP1$790
      DO 10 IR=2,10                                                     APP1$800
          IF(.NOT.(Z.EQ.4.0))GO TO 6                                    APP1$810
               IF(.NOT.(IR.EQ.2))GO TO 3                                APP1$820
                    RF=0.822                                            APP1$830
               GO TO 7                                                  APP1$840
    3          CONTINUE                                                 APP1$850
               IF(.NOT.(IR.EQ.3))GO TO 4                                APP1$860
                    RF=0.887                                            APP1$870
               GO TO 7                                                  APP1$880
    4          CONTINUE                                                 APP1$890
               IF(.NOT.(IR.EQ.4))GO TO 5                                APP1$900
                    RF=0.950                                            APP1$910
               GO TO 7                                                  APP1$920
    5          CONTINUE                                                 APP1$930
               IF(.NOT.(IR.EQ.5))GO TO 6                                APP1$940
                    RF=0.992                                            APP1$950
               GO TO 7                                                  APP1$960
```

AD-A132 414 PRELIMINARY PROPELLER SELECTION USING THE WAGENINGEN B-SCREW SERIES AND A GENERAL PURPOSE NON-LINEAR OPTIMIZER(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA M P SMITH JUN 83 F/G 13/10 NL

3/4

UNCLASSIFIED





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

```
    6       CONTINUE                                                        APP1S570
            RF=1.00                                                         APP1S980
    7       CONTINUE                                                        APP1S590
            DENOM=SQRT(((RF*PDIVD)**2)+(PII**2))                            APP2C000
            HAPN(IR)=(BMT(IR)*(PII/DENOM))+                                 APP2C010
           1         (BMC(IR)*((RF*PDIVD)/DENOM))                           APP2CC20
            HAPL(IR)=(BMT(IR)*((RF*PDIVD)/DENOM))-                          APP2C030
           1         (BMC(IR)*(PII/DENOM))                                  APP2CC40
            GO TO 9                                                         APP2CC50
    8       CONTINUE                                                        APP2C060
            DENOM=SQRT((PDIVC**2)+(PII**2))                                 APP2CC70
            HAPN(IR)=(BMT(IR)*(PII/DENOM))+                                 APP2C080
           1         (BMC(IR)*(PDIVD/DENOM))                                APP2C090
            HAPL(IR)=(BMT(IR)*(PDIVD/DENOM))-                               APP2C100
           1         (BMC(IR)*(PII/DENOM))                                  APP2C110
    9       CONTINUE                                                        APP2C120
   10   CONTINUE                                                            APP2C130
        RETURN                                                              APP2C140
        END                                                                 APP2C150
```

```
      SUBROUTINE JCNA(RJ,RJCNL,RJCNU)                                   APP2C180
                                                                        APP2C190
C     SUBROUTINE: JCNA                  DATE OF LAST REVISION: FEB 83   APP2C200
                                                                        APP2C210
C     INPUT           OUTPUT            DEFINITION                      APP2C220
                                                                        APP2C230
C     RJ                                ADVANCE COEFFICIENT             APP2C240
C                     RJCNL             CONSTRAINT VARIABLE FOR AD-     APP2C250
C                                       VANCE COEFFICIENT(LOWER BOUND   APP2C260
C                                       (RJCNL<0)                       APP2C270
C                     RJCNU             CONSTRAINT VARIABLE FOR AD-     APP2C280
C                                       VANCE COEFFICIENT(UPPER BOUND   APP2C290
C                                       (RJCNU)                         APP2C300
C                                                                       APP2C310
      REAL*4 RJ,RJCON,RJCNL,RJCNU                                       APP2C320
C                                                                       APP2C330
C     DETERMINE CONSTRAINT VARIABLE FOR ADVANCE COEFFICIENT CONSTRAINT  APP2C340
C                                                                       APP2C350
      RJCON=RJ/1.E                                                      APP2C360
      RJCNL=C.C-R.CON                                                   APP2C370
      RJCNU=RJCON-1.0                                                   APP2C380
      RETURN                                                            APP2C390
      END
```

```
      SUBROUTINE OPWEFF(RJ,KT,KQ,ETAO)                                  APP2C420
C                                                                       APP2C430
C     SUBROUTINE: OPWEFF                DATE OF LAST REVISION: FEB 83   APP2C440
C                                                                       APP2C450
C     INPUT              OUTPUT         DEFINITION                     APP2C460
C                                                                       APP2C470
C     RJ                                ADVANCE RATIO                  APP2C480
C     KT                                THRUST COEFFICIENT             APP2C490
C     KQ                                TORQUE COEFFICIENT             APP2C500
C                        ETAO           OPEN WATER EFFICIENCY          APP2C510
C                                                                       APP2C520
      REAL*4 RJ,KT,KQ,ETAO,PII                                          APP2C530
      PII=3.141592654                                                   APP2C540
C                                                                       APP2C550
C     CALCULATE OPEN WATER EFFICIENCY                                   APP2C560
C                                                                       APP2C570
      IF(KT.LE.0.0)KT=0.0                                               APP2C580
      IF(KQ.LE.0.0)KQ=0.0001                                            APP2C590
      ETAO=(RJ*KT)/(2.0*PII*KQ)                                         APP2C600
      RETURN                                                            APP2C610
      END                                                               APP2C620
```

```
      SUBROUTINE RDCAL(RDIA)                                                    APP2C650
C                                                                               APP2C660
C     SUBROUTINE:  RDCAL                    DATE OF LAST REVISION: FEB 83       APP2C670
C                                                                               APP2C680
C     INPUT              OUTPUT             DEFINITION                        APP2C690
C                                                                               APP2C700
C     V                                     VELOCITY  (FT/SEC)                APP2C710
C     N                                     PROPELLER REVOLUTION RATE(RPM)    APP2C720
C     RJ                                    ADVANCE RATIO                     APP2C730
C     WT                                    WAKE FRACTION                     APP2C740
C                        RDIA               PROPELLER DIAMETER (FEET)         APP2C750
C                                                                               APP2C760
      REAL*4  ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,                     APP2C770
     1        RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,            APP2C780
     2        POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                   APP2C790
     3        VK,TC,WT,Z,WATRC,WATNU,TEMP,NOSCRW,HCL,PATM,                      APP2C800
     4        PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                      APP2C810
     5        RDIA                                                              APP2C820
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,       APP2C830
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,           APP2C840
     2AEAOCV,TCSTRS,RJ                                                         APP2C850
      COMMON /PARAM/VK,TC,WT,Z,WATRC,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,         APP2C860
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                     APP2C870
C                                                                               APP2C880
C     CALCULATE PROPELLER DIAMETER                                              APP2C890
C                                                                               APP2C900
      RDIA=(V*(1.0-WT))/((N/60.0)*RJ)                                           APP2C910
      RETURN                                                                    APP2C920
      END                                                                       APP2C930
                                                                                APP2C940
```

```
      SUBROUTINE REYCNA(R75R,R75RCL,R75RCU)                              APP20970
C                                                                        APP20980
C     SUBROUTINE: REYCNA                    DATE OF LAST REVISION: FEB 83APP20990
C                                                                        APP21000
C     INPUT          OUTPUT                 DEFINITION                  APP21010
C                                                                        APP21020
C     R75R                                  REYNOLES NO. 3/4 RADIUS     APP21030
C                                           (CORRECTED FOR T/C 3/4 RADIUSAPP21040
C                    R75RCL                 CONSTRAINT VARIABLE FOR REY-APP21050
C                                           NOLDS NO.(CORRECTED)        APP21060
C                                           (LOWER BOUND) (R75RCL<0)    APP21070
C                    R75RCU                 CONSTRAINT VARIABLE FOR REY-APP21080
C                                           NOLDS NO. (CORRECTED)       APP21090
C                                           (UPPER BOUND) (R75RCU<0)    APP21100
C                                                                       APP21110
      REAL*4 R75R,R75RCN,R75RCL,R75RCU                                   APP21120
C                                                                        APP21130
C     DETERMINE CONSTRAINT VARIABLE FOR CORRECTED REYNOLDS NO. CONSTRAINAPP21140
C                                                                        APP21150
      R75RCN=R75R/200000.0                                               APP21160
      R75RCL=1.0-R75RCN                                                  APP21170
      R75RCU=R75RCN-1000.0                                               APP21180
      RETURN                                                             APP21190
      END                                                                APP21200
```

```
      SUBROUTINE REY75R(C75R,R75R)                                       APP21230
C                                                                        APP21240
CCC   SUBROUTINE:  REY75R                    DATE OF LAST REVISION: FEB 83APP21250
CCC                                                                      APP21260
CCC   INPUT            OUTPUT                DEFINITION                  APP21270
CCC                                                                      APP21280
CCC   C75R                                   CHORD LENGTH AR 3/4 RADIUS  APP21290
CCC                                                  (FEET)              APP21300
CCC   N                                      PROPELLER REVOLUTIONS (RPM) APP21310
CCC   DIA                                    PROPELLER DIAMETER (FEET)   APP21320
CCC   Z                                      NO. OF BLADES               APP21330
CCC   TC75R                                  BLADE SECTION THICKNESS-TO- APP21340
CCC                                          CHORD RATIO AT 3/4 RADIUS   APP21350
CCC   AEDVAD                                 EXPANDED AREA RATIO         APP21360
CCC   WATNU                                  KINEMATIC VISCOSITY         APP21370
CCC                  R75R                    REYNOLDS NO. AT 3/4 RADIUS  APP21380
CCC                                          CORRECTED FOR CORRECTED FOR APP21390
C                                            BLADE THICKNESS EFFECTS     APP21400
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,               APP21410
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEADCL,AEADCU,TC75CL,TC75CU,      APP21420
     2       POWBAL,DIACNU,AEADCV,TCSTRS,RJ,                             APP21430
     3       VK,TC,WT,Z,WATRU,WATNU,TEMP,NCSCRW,HCL,PATM,                APP21440
     4       PWATVA,PROMAT,DIALIM,ETARR,AEACMN,TC75MN,SC,                APP21450
     5       C75R,PII,VA,R75RUN,TC75WS,NUM,DENOM,R75R                    APP21460
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP21470
     1RJCNU,R75RCL,R75RCU,AEADCL,AEADCU,TC75CL,TC75CU,POWBAL,DIACNU,     APP21480
     2AEACCV,TCSTRS,RJ                                                   APP21490
      COMMON /PARAM/VK,TC,WT,Z,WATRU,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA,  APP21500
     1PROMAT,DIALIM,ETARR,AEACMN,TC75MN,SC                               APP21510
      PII=3.141592654                                                    APP21520
C                                                                        APP21530
CCC   CALCULATE SPEED OF ADVANCE                                         APP21540
C                                                                        APP21550
      VA=V*(1.0-WT)                                                      APP21560
C                                                                        APP21570
CCC   CALCULATE UNCORRECTED REYNOLDS NUMBER AT 3/4 PROPELLER RADIUS      APP21580
CCC   USING RELATION (10), REF 2                                         APP21590
C                                                                        APP21600
      R75RUN=(1.0/WATNU)*C75R*SQRT((VA**2)+((.75*PII*(N/60.0)*DIA)**2)) APP21610
C                                                                        APP21620
CCC   DETERMINE BLADE THICKNESS-TO-CHORD RATIC BASED ON A SPECIFIC "Z" &APP21630
CCC   "AEDVAC" USING RELATICN (11), REF 2                                APP21640
C                                                                        APP21650
      TC75WS=((0.0185-(0.00125*Z))*Z)/(2.073*AEDVAD)                     APP21660
C                                                                        APP21670
CCC   DETERMINE REYNOLDS NUMBER AT 3/4 RADIUS, CORECTED FOR BLADE        APP21680
CCC   THICKNESS-TO-CHORD RATIO "TC75R", USING RELATION (12), REF 2       APP21690
C                                                                        APP21700
```

```
      NUM=1.0+(2.C*TC75WS)                                                    APP21710
      DENOM=1.C+(2.0*TC75R)                                                   APP21720
      R75R=EXP(4.6052+((SQRT(NUM/DENOM))*(ALOG(R75RUN)-4.6052)))              APP21730
      RETURN                                                                  APP21740
      END                                                                     APP21750
```

```
      SUBROUTINE RJCAL(J)                                                   APP21780
                                                                            APP21790
C                                                                           APP21600
C     SUBROUTINE:  RJCAL                    DATE OF LAST REVISION: FEB 83   APP21810
C                                                                           APP21820
C     INPUT              OUTPUT             DEFINITION                     APP21830
C                                                                           APP21840
C     V                                     VELOCITY  (FT/SEC)             APP21850
C     DIA                                   PROPELLER DIAMETER  (FEET)     APP21860
C     N                                     PROPELLER REVOLUTION RATE(RPM) APP21870
C     WT                                    WAKE FRACTION                  APP21880
C                        J                  ADVANCE RATIO                  APP21890
C                                                                           APP21900
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,                  APP21910
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEACCU,TC75CL,TC75CU,         APP21920
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                APP21930
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,                   APP21940
     4       PWATVA,PROMAT,DIALIM,ETARR,AEADMN,TC75MN,SC,                   APP21950
     5       J                                                              APP21960
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,    APP21970
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEACCU,TC75CL,TC75CU,POWBAL,DIACNU,        APP21980
     2AEACCV,TCSTRS,RJ                                                      APP21990
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,     APP22000
     1PROMAT,DIALIM,ETARR,AEADMN,TC75MN,SC                                  APP22010
C                                                                           APP22020
C     CALCULATE ADVANCE RATIO                                               APP22030
C                                                                           APP22040
      J=(V*(1.0-WT))/(DIA*(N/60.0))                                         APP22050
      RETURN                                                                APP22060
      END                                                                   APP22070
```

```
      SUBROUTINE RNCAL(RN)                                                  APP22100
                                                                            APP22110
C                                                                           APP22120
C     SUBROUTINE:  RNCAL                    DATE OF LAST REVISION: FEB 83   APP22130
C                                                                           APP22140
C     INPUT              OUTPUT             DEFINITION                     APP22150
C                                                                           APP22160
C     V                                     VELOCITY  (FT/SEC)             APP22170
C     DIA                                   PROPELLER DIAMETER  (FEET)     APP22180
C     RJ                                    ADVANCE RATIO                  APP22190
C     WT                                    WAKE FRACTION                  APP22200
C                        RN                 PROPELLER REVOLUTION RATE(RPM) APP22210
C                                                                           APP22220
      REAL*4 ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,                  APP22230
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,         APP22240
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                APP22250
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,                   APP22260
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                   APP22270
     5       RN                                                             APP22280
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,    APP22290
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,        APP22300
     2AEACCV,TCSTRS,RJ                                                      APP22310
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA,     APP22320
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                  APP22330
                                                                            APP22340
C     CALCULATE PROPELLER REVOLUTION RATE                                   APP22350
C                                                                           APP22360
      RN=60.0*((V*(1.0-WT))/(DIA*RJ))                                       APP22370
      RETURN                                                                APP22380
      END                                                                   APP22390
```

```
      SUBROUTINE SIGNDS                                                 APP22420
                                                                        APP22430
C     SUBROUTINE: SIGNDS                DATE OF LAST REVISION: APR 83   APP22440
                                                                        APP22450
C     INPUT              OUTPUT         DEFINITION                      APP22460
                                                                        APP22470
C     COMMON /AREELD/                   BLADE SECTION AREAS (FEET**2)   APP22480
C     COMMON /VALL1/                    ORDINATE OF CRITICAL POINT NO.  APP22490
C                                       1 ON BLADE SECTION PERIPHERY    APP22500
C                                       WITH RESPECT TO A SYSTEM OF     APP22510
C                                       AXES PARALLEL AND NORMAL TO     APP22520
C                                       PITCH-REFERENCE LINE WITH ORI-  APP22530
C                                       GIN AT THE CENTROID OF THE      APP22540
C                                       SECTION (FEET)                  APP22550
C     COMMON /VAL21/                    ABCISSA OF CRITICAL POINT NO.   APP22560
C                                       1 ON BLADE SECTION PERIPHERY    APP22570
C                                       WITH RESPECT TO A SYSTEM OF     APP22580
C                                       AXES PARALLEL AND NORMAL TO     APP22590
C                                       PITCH-REFERENCE LINE WITH ORI-  APP22600
C                                       GIN AT THE CENTROID OF THE      APP22610
C                                       SECTION (FEET)                  APP22620
C     COMMON /VALL2/                    ORDINATE OF CRITICAL POINT NO.  APP22630
C                                       2 ON BLADE SECTION PERIPHERY    APP22640
C                                       WITH RESPECT TO A SYSTEM OF     APP22650
C                                       AXES PARALLEL AND NORMAL TO     APP22660
C                                       PITCH-REFERENCE LINE WITH ORI-  APP22670
C                                       GIN AT THE CENTROID OF THE      APP22680
C                                       SECTION (FEET)                  APP22690
C     COMMON /VAL22/                    ABCISSA OF CRITICAL POINT NO.   APP22700
C                                       2 ON BLADE SECTION PERIPHERY    APP22710
C                                       WITH RESPECT TO A SYSTEM OF     APP22720
C                                       AXES PARALLEL AND NORMAL TO     APP22730
C                                       PITCH-REFERENCE LINE WITH ORI-  APP22740
C                                       GIN AT THE CENTROID OF THE      APP22750
C                                       SECTION (FEET)                  APP22760
C     COMMON /VALL3/                    ORDINATE OF CRITICAL POINT NO.  APP22770
C                                       3 ON BLADE SECTION PERIPHERY    APP22780
C                                       WITH RESPECT TO A SYSTEM OF     APP22790
C                                       AXES PARALLEL AND NORMAL TO     APP22800
C                                       PITCH-REFERENCE LINE WITH ORI-  APP22810
C                                       GIN AT THE CENTROID OF THE      APP22820
C                                       SECTION (FEET)                  APP22830
C     COMMON /VAL23/                    ABCISSA OF CRITICAL POINT NO.   APP22840
C                                       3 ON BLADE SECTION PERIPHERY    APP22850
C                                       WITH RESPECT TO A SYSTEM OF     APP22860
C                                       AXES PARALLEL AND NORMAL TO     APP22870
C                                       PITCH-REFERENCE LINE WITH ORI-  APP22880
C                                       GIN AT THE CENTROID OF THE      APP22890
```

```
C
C     COMMON /VALL4/
C
C
C
C
C
C     COMMON /VALB4/
C
C
C
C
C
C     COMMON /A2MCMX/
C
C
C
C     COMMON /A2MCMY/
C
C
C
C     COMMON /HYDMOMN/
C
C     COMMON /HYDMOML/
C
C     COMMON /CFGFD/
C
C
C
C     COMMON /CMCEN/
C
C
C
C
C     COMMON /CMCEL/
C
C
C
C
C
C
```

```
C                       COMMON /STRES1/   DIRECT STRESS AT CRITICAL      APP23380
C                                         POINT 1 AT BLADE SECTIONS      APP23390
C                                         ALONG THE PROPELLER RADIUS     APP23400
C                                         (LBF/FT**2)                    APP23410
C                       COMMON /STRES2/   DIRECT STRESS AT CRITICAL      APP23420
C                                         POINT 2 AT BLADE SECTIONS      APP23430
C                                         ALONG THE PROPELLER RADIUS     APP23440
C                                         (LBF/FT**2)                    APP23450
C                       COMMON /STRES3/   DIRECT STRESS AT CRITICAL      APP23460
C                                         POINT 3 AT BLADE SECTIONS      APP23470
C                                         ALONG THE PROPELLER RADIUS     APP23480
C                                         (LBF/FT**2)                    APP23490
C                       COMMON /STRES4/   DIRECT STRESS AT CRITICAL      APP23500
C                                         POINT 4 AT BLADE SECTIONS      APP23510
C                                         ALONG THE PROPELLER RADIUS     APP23520
C                                         (LBF/FT**2)                    APP23530
      REAL*4 AREA(10),RIXXNA(10),RIYYNA(10),                             APP23540
     1       U1(10),U2(10),U3(10),U4(10),W1(10),W2(10),W3(10),W4(10),    APP23550
     2       HMPN(10),HMPL(10),CMCBN(10),CMCBL(10),BIGNO(10)             APP23560
      REAL*4 SIGCF(10),TOTBMA(10),TOTBML(10),                            APP23570
     1       SIG1(10),SIG2(10),SIG3(10),SIG4(10)                         APP23580
      INTEGER*4 IR                                                       APP23590
      COMMON /AREELD/AREA                                                APP23600
      COMMON /VALL1/U1                                                   APP23610
      COMMON /VALL2/U2                                                   APP23620
      COMMON /VALL3/U3                                                   APP23630
      COMMON /VALL4/U4                                                   APP23640
      COMMON /VALW1/W1                                                   APP23650
      COMMON /VALW2/W2                                                   APP23660
      COMMON /VALW3/W3                                                   APP23670
      COMMON /VALW4/W4                                                   APP23680
      COMMON /A2MCMX/RIYYNA                                              APP23690
      COMMON /A2MCMY/RIXXNA                                              APP23700
      COMMON /HYMCMN/HMPN                                                APP23710
      COMMON /HYMCML/HMPL                                                APP23720
      COMMON /CFGEMN/CMCBN                                               APP23730
      COMMON /CFGEML/CMCBL                                               APP23740
      COMMON /CFGFC/BIGNO                                                APP23750
      COMMON /STRES1/SIG1                                                APP23760
      COMMON /STRES2/SIG2                                                APP23770
      COMMON /STRES3/SIG3                                                APP23780
      COMMON /STRES4/SIG4                                                APP23790
C                                                                        APP23800
C     CALCULATE DIRECT STRESS (LBF/FT**2) DUE TO CENTRIFUGAL FORCE FOR   APP23810
C     BLADE SECTIONS ALONG THE PROPELLER RADIUS                          APP23820
C                                                                        APP23830
      DO 1 IR=2,9                                                        APP23840
         SIGCF(IR)=BIGNO(IR)/AREA(IR)                                    APP23850
```

```
    1 CONTINUE                                                                  APP23860
C                                                                               APP23870
CCC   CALCULATE TOTAL BENDING MOMENT COMPONENT (FT-LBF), PARALLEL TO            APP23880
CCC   PITCH REFERENCE (CHORD) LINE, IMPOSED BY HYDRODYNAMIC AND                 APP23890
CCC   CENTRIFUGAL LOADING                                                       APP23900
C                                                                               APP23910
      DO 2 IR=2,9                                                               APP23920
        TOTBMN(IR)=HMBN(IR)+CMOBN(IR)                                           APP23930
    2 CONTINUE                                                                  APP23940
C                                                                               APP23950
CCC   CALCULATE TOTAL BENDING MOMENT COMPONENT (FT-LBF), NORMAL TO              APP23960
CCC   PITCH REFERENCE (CHORD) LINE, IMPOSED BY HYDRODYNAMIC AND                 APP23970
CCC   CENTRIFUGAL LOADING                                                       APP23980
C                                                                               APP23990
      DO 3 IR=2,9                                                               APP24000
        TOTBML(IR)=HMBL(IR)+CMOBL(IR)                                           APP24010
    3 CONTINUE                                                                  APP24020
C                                                                               APP24030
CCC   CALCULATE STRESSES (LBF/FT**2) AT CRITICAL POINTS 1, 2, 3 AND 4          APP24040
CCC   ALONG THE PROPELLER RADIUS USING RELATION (105), REF 8 , WHERE...         APP24050
CCC                                                                             APP24060
CCC   SIG1(IR)          DIRECT STRESS AT CRITICAL POINT 1 SPECIFIED BY          APP24070
CCC                     BLADE SECTION COORDINATES ( W1, U1)                     APP24080
CCC   SIG2(IR)          DIRECT STRESS AT CRITICAL POINT 2 SPECIFIED BY          APP24090
CCC                     BLADE SECTION COORDINATES ( W2, U2)                     APP24100
CCC   SIG3(IR)          DIRECT STRESS AT CRITICAL POINT 3 SPECIFIED BY          APP24110
CCC                     BLADE SECTION COORDINATES ( W3, U3)                     APP24120
CCC   SIG4(IR)          DIRECT STRESS AT CRITICAL POINT 4 SPECIFIED BY          APP24130
CCC                     BLADE SECTION COORDINATES ( W4, U4)                     APP24140
C                                                                               APP24150
      DO 4 IR=2,9                                                               APP24160
        SIG1(IR)=SIGCF(IR)+((TOTBML(IR)*(-W1(IR)))/RIYYNA(IR))+                 APP24170
     1                     ((TOTBMN(IR)*(-U1(IR)))/RIXXNA(IR))                  APP24180
        SIG2(IR)=SIGCF(IR)+((TOTBML(IR)*(-W2(IR)))/RIYYNA(IR))+                 APP24190
     1                     ((TOTBMN(IR)*(-U2(IR)))/RIXXNA(IR))                  APP24200
        SIG3(IR)=SIGCF(IR)+((TOTBML(IR)*(-W3(IR)))/RIYYNA(IR))+                 APP24210
     1                     ((TOTBMN(IR)*(-U3(IR)))/RIXXNA(IR))                  APP24220
        SIG4(IR)=SIGCF(IR)+((TOTBML(IR)*(-W4(IR)))/RIYYNA(IR))+                 APP24230
     1                     ((TOTBMN(IR)*(-U4(IR)))/RIXXNA(IR))                  APP24240
    4 CONTINUE                                                                  APP24250
      RETURN                                                                    APP24260
      END                                                                       APP24270
```

```
      SUBROUTINE STRCNA(KQ,C75R,SCSTRS)                                  APP24300
C                                                                        APP24310
CCCC  INPUT              OUTPUT          DEFINITION                      APP24320
C                                                                        APP24330
CCCC  PROPAT                             PROPELLER MATERIAL IDENTIFIER   APP24340
CCCC                                        1: CAST IRON                 APP24350
CCCC                                        2: CAST STEEL                APP24360
CCCC                                        3: TYPE 2 BRONZE             APP24370
CCCC                                        4: TYPE 4 NI-AL BRONZE       APP24380
CCCC                                        5: STAINLESS STEEL           APP24390
CCCC  DIA                                PROPELLER DIAMETER (FT)         APP24400
CCCC  N                                  PROPELLER REVOLUTION RATE (RPM) APP24410
CCCC  PDIVD                              PITCH-DIAMETER RATIO            APP24420
CCCC  KQ                                 TORQUE COEFFICIENT              APP24430
CCCC  C75R                               CHORD LENGTH 3/4 RADIUS (FT)    APP24440
CCCC  NOSCRW                             NO. OF PROPELLERS               APP24450
CCCC  TC75R                              BLADE THICKNESS-TO-CHORD RATIO  APP24460
CCCC                                     3/4 RADIUS                      APP24470
CCCC                     SCSTRS          CONSTRAINT VARIABLE FOR BLADE   APP24480
CCCC                                     THICKNESS-TO-CHORD RATIO 3/4    APP24490
CCCC                                     RADIUS CONSTRAINT (TCSTRS<0)    APP24500
C                                                                        APP24510
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,               APP24520
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEADCL,AEACCU,TC75CL,TC75CU,      APP24530
     2       POWBAL,DIACNU,AEADCV,TCSTRS,RJ,                             APP24540
     3       VK,TC,WT,Z,WATRQ,WATNU,TEMP,NOSCRW,HCL,PATM,                APP24550
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SCSTRS,            APP24560
     5       C75R,KQ,PII,SC,CABSRB,PABSRB,FAC1D,FAC2D,FAC1N,T75MIN       APP24570
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL, APP24580
     1RJCNU,R75RCL,R75RCU,AEACCL,AEACCU,TC75CL,TC75CU,POWBAL,DIACNU,     APP24590
     2AEACCV,TCSTRS,RJ                                                   APP24600
      COMMON /PARAM/VK,TC,WT,Z,WATRQ,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,  APP24610
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                               APP24620
      PII=3.141592654                                                    APP24630
C                                                                        APP24640
CCCC  DETERMINE MAXIMUM ALLOWABLE STRESS (PSI) BASED ON NUMBER OF PRO-   APP24650
CCCC  PELLERS AND MATERIAL IDENTIFIER                                    APP24660
C                                                                        APP24670
      IF(.NOT.(NOSCRW.EQ.1.0)) GO TO 1                                   APP24680
           IF(PROMAT.EQ.1.0)SC=3600.0                                    APP24690
           IF(PROMAT.EQ.2.0)SC=5515.0                                    APP24700
           IF(PROMAT.EQ.3.0)SC=7200.0                                    APP24710
           IF(PROMAT.EQ.4.0)SC=8910.0                                    APP24720
           IF(PROMAT.EQ.5.0)SC=5400.0                                    APP24730
      GO TO 2                                                            APP24740
    1 CONTINUE                                                           APP24750
           IF(PROMAT.EQ.1.0)SC=3950.0                                    APP24760
           IF(PROMAT.EQ.2.0)SC=6265.0                                    APP24770
```

```
      IF(PROPAT.EQ.3.0)SC=7585.0                                        APP24760
      IF(PROPAT.EQ.4.0)SC=9430.0                                        APP24790
      IF(PROPAT.EQ.5.0)SC=5500.0                                        APP24800
    2 CONTINUE                                                          APP24810
C                                                                       APP24820
CC    DETERMINE ABSORBED POWER FOR EACH PROPELLER                       APP24830
C                                                                       APP24840
      QABSRB=ABS(KQ*WATRC*(DIA**5)*((N/60.0)**2))                       APP24850
      PABSRB=(2.0*PI*QABSRB*N)/33000.0                                  APP24860
C                                                                       APP24870
CC    CALCULATE MINIMUM REQUIRED BLADE THICKNESS-TO-CHORD RATIO AT 3/4  APP24880
CC    BLADE RADIUS USING RELATION (16), REF 2                           APP24890
C                                                                       APP24900
      FAC1D=SC*(((DIA*N)**2)/(12.788))                                  APP24910
      FAC2D=4.123*N*(DIA**3)                                            APP24920
      FAC1N=(2375.0-(1125.0*PDIVD))*PABSRB                              APP24930
      T75MIN=((((FAC1N/(FAC2D*FAC1D))**0.33333)*0.21)+0.0028)*DIA       APP24940
      TC75MN=T75MIN/C75R                                                APP24950
C                                                                       APP24960
CC    DETERMINE CONSTRAINT VARIABLE FOR BLADE THICKNESS-TO-CHORD RATIO  APP24970
CC    CONSTRAINT                                                        APP24980
C                                                                       APP24990
      SCSTRS=(TC75MN/TC75R)-1.0                                         APP25000
      RETURN                                                            APP25010
      END                                                               APP25020
```

```
      SUBROUTINE STRCNK(KQ,KT,C75R,SCSTRS)                                  APP25050
                                                                            APP25060
C     SUBROUTINE: STRCNK                    DATE OF LAST REVISION: APR 83   APP25070
C                                                                           APP25080
C     INPUT          OUTPUT                 DEFINITION                      APP25090
C                                                                           APP25100
C     PROMAT                                PROPELLER MATERIAL IDENTIFIER   APP25110
C                                             1: CAST IRON                  APP25120
C                                             2: CAST STEEL                 APP25130
C                                             3: TYPE 2 BRONZE              APP25140
C                                             4: TYPE 4 NI-AL BRONZE        APP25150
C                                             5: STAINLESS STEEL            APP25160
C     DIA                                   PROPELLER DIAMETER (FT)         APP25170
C     N                                     PROPELLER REVOLUTION RATE (RPM) APP25180
C     PDIVD                                 PITCH-DIAMETER RATIO            APP25190
C     AEDVAO                                EXPANDED AREA RATIO             APP25200
C     KQ                                    TORQUE COEFFICIENT              APP25210
C     KT                                    THRUST COEFFICIENT              APP25220
C     C75R                                  CHORD LENGTH 3/4 RADIUS (FT)    APP25230
C     NOSCRW                                NO. OF PROPELLERS               APP25240
C     TC75R                                 BLADE THICKNESS-TO-CHORD RATIO  APP25250
C                                           3/4 RADIUS                      APP25260
C                     SCSTRS                CONSTRAINT VARIABLE FOR BLADE   APP25270
C                                           THICKNESS-TO-CHORD RATIO 3/4    APP25280
C                                           RADIUS CONSTRAINT (SCSTRS<0)    APP25290
                                                                            APP25300
      REAL*4  ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,                 APP25310
     1        RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEACCU,TC75CL,TC75CU,        APP25320
     2        PUMBAL,DIACNU,AEAOCV,TCSTRS,                                  APP25330
     3        VK,TC,WT,Z,WATRC,WATNU,TEMP,NOSCRW,HCL,PATM,                  APP25340
     4        FWATVA,PROMAT,DIALIM,ETARR,                                   APP25350
     5        RJ,C75R,R75R,KT,KQ                                            APP25360
      REAL*4  T00R,T1XR,T20R,T30R,T40R,T50R,T60R,T70R,T75R,T80R,T90R,        APP25370
     1        T100R,RAT                                                     APP25380
      REAL*4  CR(10),AR(10),BR(10),PLF(10),PLA(10),TR(10),V1F(10,11),       APP25390
     1        V2F(10,11),V1A(10,10),V2A(10,10),YFACE(11),YBACK(11),         APP25400
     2        HA(10),Y(11),DELPA(10),AA(10),DLPASM,XA(10),YA(10),SUMAA,     APP25410
     3        SUMAXA,SUMAYA,SMAX2A,SMAY2A,HF(11),DELPF(11),AF(11),DLPFSM,   APP25420
     4        XF(11),YF(11),SUMAF,SUMAXF,SUMAYF,SMAX2F,SMAY2F,AREA(10),     APP25430
     5        XMT(10),YPRL(10),RIXXNA(10),RIYYNA(10),XCG(10),YCG(10)        APP25440
      REAL*4  U1(10),U2(10),U3(10),U4(10),W1(10),W2(10),W3(10),W4(10),      APP25450
     1        YBK,YFC                                                       APP25460
      REAL*4  HMPN(10),HMPL(10),CMCBN(10),CMCEL(10),BIGNO(10),SIG1(10),     APP25470
     1        SIG2(10),SIG3(10),SIG4(10),TC75MA,TC75WS,SCSTRS,SC            APP25480
      INTEGER*4 IF,KOUNT                                                    APP25490
      LOGICAL OKAY1,OKAY2,OKAY3,OKAY4                                       APP25500
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,    APP25510
     1RJCNU,R75RCL,R75RCU,AEACCL,AEAOCU,TC75CL,TC75CU,PUMBAL,DIACNU,        APP25520
```

```
     2AEACCV,TCSTFS,RJ                                                  APP25530
      COMMON /FARAM/VK,TC,WT,Z,WATRQ,WATNL,TEMP,NCSCRW,HCL,PATM,PWATVA,  APP25540
     1PROMAT,CIALIM,ETARR,AEACMN,TC75MN,SC                              APP25550
      COMMON /THICC/TCOR,T1XR,T20R,T30R,T40R,T50R,T60R,T70R,T75R,T80R,   APP25560
     1T90R,T1CCR,FAT                                                    APP25570
      COMMON /AREELD/AREA                                               APP25580
      COMMON /CGX/XCG                                                   APP25590
      COMMON /CGY/YCG                                                   APP25600
      COMMON /CRDINT/CR                                                 APP25610
      COMMON /VALL1/U1                                                  APP25620
      COMMON /VALL2/U2                                                  APP25630
      COMMON /VALL3/U3                                                  APP25640
      COMMON /VALL4/U4                                                  APP25650
      COMMON /VALW1/W1                                                  APP25660
      COMMON /VALW2/W2                                                  APP25670
      COMMON /VALW3/W3                                                  APP25680
      COMMON /VALW4/W4                                                  APP25690
      COMMON /A2MCMX/RIYYNA                                             APP25700
      COMMON /A2MCMY/RIXXNA                                             APP25710
      COMMON /HYMCMN/HMPN                                               APP25720
      COMMON /HYMCML/HMPL                                               APP25730
      COMMON /CFGEMN/CMCBN                                              APP25740
      COMMON /CFGEML/CMCBL                                              APP25750
      COMMON /CFGFD/BIGNO                                               APP25760
      COMMON /STRES1/SIG1                                               APP25770
      COMMON /STRES2/SIG2                                               APP25780
      COMMON /STRES3/SIG3                                               APP25790
      COMMON /STRES4/SIG4                                               APP25800
C                                                                       APP25810
CC    DETERMINE MAXIMUM ALLOWABLE STRESS (PSI) BASED UPON THE NUMBER OF APP25820
CC    PROPELLERS AND TYPE OF MATERIAL                                   APP25830
C                                                                       APP25840
      IF(.NOT.(NOSCRW.EQ.1.0)) GO TO 1                                  APP25850
           IF(PROMAT.EQ.1.0)SC=3600.0                                   APP25860
           IF(PROMAT.EQ.2.0)SC=5515.0                                   APP25870
           IF(PROMAT.EQ.3.0)SC=7200.0                                   APP25880
           IF(PROMAT.EQ.4.0)SC=8910.0                                   APP25890
           IF(PROMAT.EQ.5.0)SC=5400.0                                   APP25900
      GO TO 2                                                           APP25910
    1 CONTINUE                                                          APP25920
           IF(PROMAT.EQ.1.0)SC=3950.0                                   APP25930
           IF(PROMAT.EQ.2.0)SC=6265.0                                   APP25940
           IF(PROMAT.EQ.3.0)SC=7585.0                                   APP25950
           IF(PROMAT.EQ.4.0)SC=9430.0                                   APP25960
           IF(PROMAT.EQ.5.0)SC=5500.0                                   APP25970
    2 CONTINUE                                                          APP25980
C                                                                       APP25990
C     INITIALIZE MINIMUM REQUIRED BLADE THICKNESS-TO-CHORD RATIO AT 3/4 APP26000
```

```
C       PROPELLER RADIUS TO A PERCENTAGE OF THE RATIO FOR THE SERIES       APP26010
C       PROPELLER USING RELATION (11), REF 2                               APP26020
C                                                                          APP26030
        TC75MN= ((0.0185-(0.00125*Z))*Z)/(2.073*AEDVAD)                    APP26040
C                                                                          APP26050
C       ITERATE FOR MINIMUM REQUIRED BLADE THICKNESS-TO-CHORD RATIO AT 3/4 APP26060
C       PROPELLER RADIUS BASED UPON THE CRITERIA THAT THE DIRECT STRESSES  APP26070
C       CALCULATED AT CRITICAL POINTS 1 (W1,U1), 2 (W2,U2), 3 (W3,U3) AND  APP26080
C       4 (W4,U4) DO NOT EXCEED THE MAXIMUM ALLOWABLE STRESS AS PREVIOUSLY APP26090
C       DETERMINED. ITERATE FOR A MAXIMUM OF 100 TIMES.                    APP26100
C                                                                          APP26110
        KOUNT=0                                                            APP26120
    3 CONTINUE                                                             APP26130
          TC75MN=TC75MN+0.0010                                             APP26140
          KOUNT=KOUNT+1                                                    APP26150
CC                                                                         APP26160
CC        CALCULATE MAXIMUM BLADE SECTION THICKNESS DISTRIBUTION ALONG     APP26170
CC        THE PROPELLER RADIUS                                             APP26180
CC                                                                         APP26190
          CALL TDIST(C75R,TC75MN,DIA,Z,AEDVAD)                             APP26200
CC                                                                         APP26210
CC        DETERMINE BLADE SECTION PROPERTIES                               APP26220
CC                                                                         APP26230
          CALL BLDPRP                                                      APP26240
CC                                                                         APP26250
CC        DETERMINE BENDING MOMENTS DUE TO HYDRODYNAMIC LOADING            APP26260
CC                                                                         APP26270
          CALL HYDLD(KQ,KT)                                                APP26280
CC                                                                         APP26290
CC        DETERMINE FORCE AND BENDING MOMENTS DUE TO CENTRIFUGAL           APP26300
CC        LOADING                                                          APP26310
CC                                                                         APP26320
          CALL CNFGLD                                                      APP26330
CC                                                                         APP26340
CC        DETERMINE STRESS (LBF/FT2) AT CRITICAL POINTS 1,2,3,4            APP26350
CC                                                                         APP26360
          CALL SIGNDS                                                      APP26370
CC                                                                         APP26380
CC        INITIALIZE LOGICAL VARIABLES FOR CURRENT ITERATION               APP26390
CC                                                                         APP26400
          OKAY1=.TRUE.                                                     APP26410
          OKAY2=.TRUE.                                                     APP26420
          OKAY3=.TRUE.                                                     APP26430
          OKAY4=.TRUE.                                                     APP26440
CC                                                                         APP26450
CC        CHECK STRESSES AT CRITICAL POINTS 1,2,3, AND 4 TO DETERMINE      APP26460
CC        WHETHER OR NOT MAXIMUM ALLOWABLE STRESS IS EXCEEDED              APP26470
CC                                                                         APP26480
```

```
      DO 6 IR=2,5                                                        APP26490
           IF(.NOT.(ABS(SIG1(IR)).GE.(SC*144.0)))GO TO 4                 APP26500
                OKAY1=.FALSE.                                            APP26510
 4         CONTINUE                                                      APP26520
           IF(.NOT.(ABS(SIG2(IR)).GE.(SC*144.0)))GO TO 5                 APP26530
                OKAY2=.FALSE.                                            APP26540
 5         CONTINUE                                                      APP26550
           IF(.NOT.(ABS(SIG3(IR)).GE.(SC*144.0)))GO TO 6                 APP26560
                OKAY3=.FALSE.                                            APP26570
 6         CONTINUE                                                      APP26580
           IF(.NOT.(ABS(SIG4(IR)).GE.(SC*144.0)))GO TO 7                 APP26590
                OKAY4=.FALSE.                                            APP26600
 7         CONTINUE                                                      APP26610
 8    CONTINUE                                                           APP26620
C      IF(.NOT.((OKAY1).AND.(OKAY2).AND.(OKAY3).AND.(OKAY4)))GO TO 3     APP26630
       IF(.NOT.(((OKAY1).AND.(OKAY2).AND.(OKAY3).AND.(OKAY4)).OR.        APP26640
     1      (KOUNT.EQ.100)))GO TO 3                                       APP26650
C                                                                        APP26660
CC     HAVING DETERMINED MINIMUM REQUIRED BLADE THICKNESS-TO-CHORD       APP26670
CC     RATIO AT 3/4 PROPELLER RADIUS, CALCULATE CONSTRAINT VARIABLE      APP26680
C                                                                        APP26690
       SCSTRS=(TC75MN/TC75R)-1.0                                         APP26700
       RETURN                                                            APP26710
       END                                                               APP26720
```

```
      SUBROUTINE TDIST(C75R,TC75R,DIA,Z,AEDVAC)                          APP26750
                                                                         APP26760
                                                                         APP26770
C     SUBROUTINE:  TDIST                    DATE OF LAST REVISION: MAR 83 APP26780
C                                                                        APP26790
C     INPUT              OUTPUT             DEFINITION                  APP26800
C                                                                        APP26810
C     C75R                                  CHORD LENGTH AT 3/4 RADIUS  APP26820
C                                           (FEET)                      APP26830
C     TC75R                                 BLADE SECTION THICKNESS-TO- APP26840
C                                           CHORD RATIO AT 3/4 RADIUS   APP26850
C     DIA                                   PROPELLER DIAMETER (FEET)   APP26860
C     Z                                     NO. OF PROPELLER BLADES     APP26870
C     AEDVAC                                EXPANDED AREA RATIO         APP26880
C                        COMMON /THICD/     BLADE SECTION MAXIMUM       APP26890
C                                           THICKNESSES ALONG PROPELLER APP26900
C                                           RADIUS (FEET)               APP26910
      REAL*4 T00R,T1XR,T20R,T30R,T40R,T50R,T60R,T70R,T75R,T80R,T90R,      APP26920
     1       T1CCR,RAT,C75R,TC75R,DIA,Z,AEDVAC,T75RWS                    APP26930
      COMMON /THICD/T00R,T1XR,T20R,T30R,T40R,T50R,T60R,T70R,T75R,T80R,    APP26940
     1T90R,T1CCR,RAT                                                     APP26950
                                                                         APP26960
C     CALCULATE MAXIMUM THICKNESS AT 3/4 RADIUS                          APP26970
C                                                                        APP26980
      T75R=TC75R*C75R                                                    APP26990
C                                                                        APP27000
C     CALCULATE MAXIMUM THICKNESS AT 3/4 RADIUS FOR SERIES PROPELLER     APP27010
C     USING RELATION (11), REF 2                                         APP27020
C                                                                        APP27030
      T75RWS=DIA*(0.0185-(0.00125*Z))                                    APP27040
C                                                                        APP27050
C     CALCULATE RATIO OF MAXIMUM THICKNESSES AT 3/4 RADIUS               APP27060
C                                                                        APP27070
      RAT=T75R/T75RWS                                                    APP27080
C                                                                        APP27090
C     GENERATE A DISTRIBUTION OF BLADE SECTION MAXIMUM THICKNESSES ALONG APP27100
C     THE PROPELLER RADIUS BASED ON THE RATIO CALCULATED ABOVE           APP27110
C                                                                        APP27120
      IF(.NOT.(Z.EQ.3.0))GO TO 1                                         APP27130
           T1CCR=0.050C*DIA                                              APP27140
           T1XR=RAT*DIA*(0.05364-(0.0041*Z))                             APP27150
      GO TO 5                                                            APP27160
    1 CONTINUE                                                           APP27170
      IF(.NOT.(Z.EQ.4.0))GO TO 2                                         APP27180
           T1CCR=0.045*DIA                                               APP27190
           T1XR=RAT*DIA*(0.054646-(0.004165*Z))                          APP27200
      GO TO 5                                                            APP27210
    2 CONTINUE                                                           APP27220
```

```
      IF(.NOT.(Z.EQ.5.0))GO TO 3                                        APP27230
            TCCR=0.040*DIA                                              APP27240
            T1XR=RAT*DIA*(0.054646-(0.004165*Z))                        APP27250
      GO TO 5                                                           APP27260
    3 CONTINUE                                                          APP27270
      IF(.NOT.(Z.EQ.6))GO TO 4                                          APP27280
            TCCR=0.035*DIA                                              APP27290
            T1XR=RAT*DIA*(0.054646-(0.004165*Z))                        APP27300
      GO TO 5                                                           APP27310
    4 CONTINUE                                                          APP27320
            TCCR=0.035*DIA                                              APP27330
            T1XR=RAT*DIA*(0.05384-(0.0041*Z))                           APP27340
    5 CONTINUE                                                          APP27350
      T2OR=RAT*DIA*(0.0526-(0.0040*Z))                                  APP27360
      T3OR=RAT*DIA*(0.0464-(0.0035*Z))                                  APP27370
      T4OR=RAT*DIA*(0.0402-(0.0030*Z))                                  APP27380
      T5OR=RAT*DIA*(0.0340-(0.0025*Z))                                  APP27390
      T6OR=RAT*DIA*(0.0278-(0.0020*Z))                                  APP27400
      T7OR=RAT*DIA*(0.0216-(0.0015*Z))                                  APP27410
      T8OR=RAT*DIA*(0.0154-(0.0010*Z))                                  APP27420
      T9OR=RAT*DIA*(0.0092-(0.0005*Z))                                  APP27430
      T10OR=RAT*DIA*(0.0030-(0.0000*Z))                                 APP27440
      RETURN                                                            APP27450
      END                                                               APP27460
```

```
      SUBROUTINE WGTCAL(C75R)                                                  APP27490
C                                                                              APP27500
C     SUBROUTINE:  WGTCAL                    DATE OF LAST REVISION: MAR 83     APP27510
C                                                                              APP27520
C     INPUT              OUTPUT              DEFINITION                        APP27530
C                                                                              APP27540
C     AEDVAD                                 EXPANDED AREA RATIO               APP27550
C     C75R                                   CHORD LENGTH AT 3/4 RADIUS        APP27560
C                                            (FEET)                            APP27570
C     DIA                                    PROPELLER DIAMETER (FEET)         APP27580
C     PRCMAT                                 PROPELLER MATERIAL IDENTIFIER     APP27590
C                                               1: CAST IRON                   APP27600
C                                               2: CAST STEEL                  APP27610
C                                               3: TYPE 2 BRONZE               APP27620
C                                               4: TYPE 4 NI-AL BRONZE         APP27630
C                                               5: STAINLESS STEEL             APP27640
C     TC75R                                  BLADE SECTION THICKNESS-TO-       APP27650
C                                            CHORD RATIO AT 3/4 RADIUS         APP27660
C     Z                                      NO. OF PROPELLER BLADES           APP27670
C                        WEIGHT              PROPELLER BLADE WEIGHT (LBF)      APP27680
C                                                                              APP27690
      REAL*4 ETAD,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,                     APP27700
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEADCL,AEADCU,TC75CL,TC75CU,            APP27710
     2       POWBAL,DIACNU,AEADCV,TCSTRS,                                      APP27720
     3       VK,TC,WT,Z,WATRQ,WATNU,TEMP,NCSCRW,HCL,PATM,                      APP27730
     4       PWATVA,PRCMAT,DIALIM,ETARR,                                       APP27740
     5       RJ,C75R,R75R,KT,KQ                                                APP27750
      REAL*4 T00R,T1XR,T20R,T30R,T40R,T50R,T6CR,T70R,T75R,T80R,T90R,            APP27760
     1       T1C0R,RAT                                                         APP27770
      REAL*4 CR(10),AR(10),BR(10),PLF(10),PLA(10),TR(10),V1F(10,11),           APP27780
     1       V2F(10,11),V1A(10,10),V2A(10,10),YFACE(11),YBACK(11),             APP27790
     2       WA(10),Y(11),DELPA(10),AA(10),DLPASM,XA(10),YA(10),SUMAA,         APP27800
     3       SUMAXA,SUMAYA,SMAX2A,SMAY2A,WF(11),DELPF(11),AF(11),DLPFSM,       APP27810
     4       XF(11),YF(11),SUMAF,SUMAXF,SUMAYF,SMAX2F,SMAY2F,AREA(10),         APP27820
     5       XMT(10),YPRL(10),RIXXNA(10),RIYYNA(10),XCG(10),YCG(10)            APP27830
      REAL*4 U1(10),U2(10),U3(10),U4(10),W1(10),W2(10),W3(10),W4(10),          APP27840
     1       WBK,WFC                                                           APP27850
      REAL*4 WC,VCLBLD                                                         APP27860
      COMMON /GLOBCM/ETAD,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,       APP27870
     1RJCNU,R75RCL,R75RCU,AEADCL,AEADCU,TC75CL,TC75CU,POWBAL,DIACNU,           APP27880
     2AEADCV,TCSTRS,RJ                                                         APP27890
      COMMON /PARAM/VK,TC,WT,Z,WATRQ,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA,        APP27900
     1PRCMAT,DIALIM,ETARR,AEADMN,TC75MN,SC                                     APP27910
      COMMON /THICC/T00R,T1XR,T20R,T30R,T40R,T50R,T60R,T70R,T75R,T80R,          APP27920
     1T90R,T1C0R,RAT                                                           APP27930
      COMMON /AREELD/AREA                                                      APP27940
      COMMON /CGX/XCG                                                          APP27950
      COMMON /CGY/YCG                                                          APP27960
```

```
      COMMON /CRDINT/CR                                                 APP27570
      COMMON /VALL1/U1                                                  APP27580
      COMMON /VALL2/U2                                                  APP27590
      COMMON /VALL3/U3                                                  APP28000
      COMMON /VALL4/U4                                                  APP28010
      COMMON /VALB1/W1                                                  APP28020
      COMMON /VALB2/W2                                                  APP28030
      COMMON /VALB3/W3                                                  APP28040
      COMMON /VALB4/W4                                                  APP28050
      COMMON /A2MCMX/RIYYNA                                             APP28060
      COMMON /A2MCMY/RIXXNA                                             APP28070
C                                                                       APP28080
CCC   DETERMINE BLADE SECTION MAXIMUM THICKNESS DISTRIBUTION            APP28090
C                                                                       APP28100
      CALL TDIST(C75R,TC75R,DIA,Z,AEOVAC)                               APP28110
C                                                                       APP28120
CCC   DETERMINE BLADE SECTION PROPERTIES                                APP28130
C                                                                       APP28140
      CALL BLDFRP                                                       APP28150
C                                                                       APP28160
CCC   DETERMINE VOLUME OF A PROPELLER BLADE                             APP28170
C                                                                       APP28180
      CALL BLDVOL(VOLBLD)                                               APP28190
C                                                                       APP28200
CCC   SPECIFY WEIGHT DENSITY OF MATERIAL SELECTED WHERE...              APP28210
CCCCC                                                                   APP28220
CCCCC PROMAT       MATERIAL              WEIGHT DENSITY (LBF/IN**3)     APP28230
CCCCC   1          CAST IRON               .260                         APP28240
CCCCC   2          CAST STEEL              .284                         APP28250
CCCCC   3          TYPE 2 BRONZE           .305                         APP28260
CCCCC   4          TYPE 4 NI-AL BRONZE     .278                         APP28270
CCCCC   5          STAINLESS STEEL         .283                         APP28280
C                                                                       APP28290
      IF(PROMAT.EQ.1.0)WD=.260                                          APP28300
      IF(PROMAT.EQ.2.0)WD=.284                                          APP28310
      IF(PROMAT.EQ.3.0)WD=.305                                          APP28320
      IF(PROMAT.EQ.4.0)WD=.278                                          APP28330
      IF(PROMAT.EQ.5.0)WD=.283                                          APP28340
C                                                                       APP28350
CCC   CALCULATE PROPELLER BLADE WEIGHT                                  APP28360
C                                                                       APP28370
      WEIGHT=VOLBLD*WD*(1728.0)                                         APP28380
      RETURN                                                            APP28390
      END                                                               APP28400
```

```
      SUBROUTINE ANALIZ(ICALC)                                          APPOC010
      INTEGER*4 ICALC                                                   APPOC020
      REAL*4 ETAD,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,              APPOC030
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEADCL,AEADCU,TC75CL,TC75CU,     APPOC040
     2       POWBAL,DIACNU,AEADCV,ICSTRS,RJ,                            APPOC050
     3       VK,TC,WT,Z,WATRC,WATNU,TEMP,NCSCRW,HCL,PATM,               APPOC060
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APPOC070
     5       C75R,R75R,KT,KQ,PD                                         APPOC080
      COMMON /GLOBCM/ETAD,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APPOC090
     1RJCNU,R75RCL,R75RCU,AEADCL,AEADCU,TC75CL,TC75CU,POWBAL,DIACNU,    APPOC100
     2AEADCV,ICSTRS,RJ                                                  APPOC110
      COMMON /PARAM/VK,TC,WT,Z,WATRD,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA, APPOC120
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APPOC130
C                                                                       APPOC140
C     THIS SUBROUTINE, COUPLED WITH COPES/CONMIN, CONSTITUTES ANALYSIS  APPOC150
C     METHOD FOR "DESIGN CASE 1" PROPELLER SELECTION PROBLEMS           APPOC160
C                                                                       APPOC170
C     INPUT-INITIALIZATION PHASE                                        APPOC180
C                                                                       APPOC190
      PII=3.14159264                                                    APPOC200
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                      APPOC210
CC                                                                      APPOC220
CC          SET "DESIGN CASE 1" PARAMETERS                              APPOC230
CC                                                                      APPOC240
CC          ENVIRONMENTAL                                               APPOC250
CC                                                                      APPOC260
            TEMP=59.0                                                   APPOC270
            WATRD=1.93E4                                                APPOC280
            WATNU=.0000122850                                           APPOC290
            PATM=14.7                                                   APPOC300
            PWATVA=.247                                                 APPOC310
CC                                                                      APPOC320
CC          PROPELLER PARAMETERS                                        APPOC330
CC                                                                      APPOC340
            Z=5.0                                                       APPOC350
            PROMAT=5.0                                                  APPOC360
CC                                                                      APPOC370
CC          HULL PARAMETERS                                             APPOC380
CC                                                                      APPOC390
            WT=0.22                                                     APPOC400
            TC=0.19                                                     APPOC410
            ETARR=1.025                                                 APPOC420
            NCSCRW=1.0                                                  APPOC430
            HCL=19.0                                                    APPOC440
            DIALIM=22.0                                                 APPOC450
CC                                                                      APPOC460
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 1"         APPOC470
CC                                                                      APPOC480
```

```
      PE=18153.0                                                        APPOC490
      VK=24.C                                                           APPOC500
      V=1.688*VK                                                        APPOC510
      AECVAC=0.85                                                       APPOC520
      DIA=22.0                                                          APPOC530
      TC75R=((0.0185-0.CC125*Z)*Z)/(2.073*AECVAC)                       APPOC540
CC                                                                      APPOC550
CC          END OF INPUT-INITIALIZATION PHASE                           APPOC560
CC                                                                      APPOC570
      GO TO 3                                                           APPOC580
C                                                                       APPOC590
C     EXECUTION PHASE                                                   APPOC600
C                                                                       APPOC610
    1 CONTINUE                                                          APPOC620
      IF(.NOT.(ICALC.EQ.2))GO TO 2                                      APPOC630
      CALL RNCAL(N)                                                     APPOC640
      CALL C75RA(C75R)                                                  APPOC650
      CALL REY75R(C75R,R75R)                                            APPOC660
      CALL CCEFSA(RJ,R75R,KT,KQ)                                        APPOC670
      CALL OPWEFF(RJ,KT,KQ,ETAO)                                        APPOC680
      CALL CALCQS(KQ,QS)                                                APPOC690
      CALL JCNA(RJ,RJCNL,RJCNU)                                         APPOC700
      CALL REYCNA(R75R,R75RCL,R75RCU)                                   APPOC710
      CALL EXTCCN(Z,AECVAD,TC75R,AEACCL,AEACCU,TC75CL,TC75CU)           APPOC720
      CALL BLPOWI(KT,PUWBAL)                                            APPOC730
      CALL DICNUA(DIACNU)                                               APPOC740
      CALL CAVCNA(KT,AEACCV)                                            APPOC750
      CALL STRCNA(KC,C75R,TCSTRS)                                       APPOC760
CC                                                                      APPOC770
CC          END OF EXECUTION PHASE                                      APPOC780
CC                                                                      APPOC790
      GO TO 3                                                           APPOC800
    2 CONTINUE                                                          APPOC810
C                                                                       APPOC820
C     OUTPUT-RESULT PHASE                                               APPOC830
C                                                                       APPOC840
      PC=(2.C*PII*QS*N)/33000.0                                         APPOC850
      WRITE(6,9000)                                                     APPOC860
      WRITE(6,9001)                                                     APPOC870
      WRITE(6,9002)TEMP,WATRO,WAINU,PATM,PWATVA                         APPOC880
      WRITE(6,9003)WT,TD,ETARR,NOSCRW,HCL,DIALIM                        APPOC890
      WRITE(6,9004)Z                                                    APPOC900
      IF(.NOT.(PROMAT.EQ.1.C))GO TO 81                                  APPOC910
          WRITE(6,9005)SC                                               APPOC920
      GO TO 86                                                          APPOC930
   81 CONTINUE                                                          APPOC940
      IF(.NOT.(PROMAT.EQ.2.0))GO TO 82                                  APPOC950
          WRITE(6,9006)SC                                               APPOC960
```

```
            GO TO 86                                                        APP00970
   82       CONTINUE                                                        APP00980
            IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                                APP00990
               WRITE(6,9007)SC                                              APP01000
            GO TO 86                                                        APP01010
   83       CONTINUE                                                        APP01020
            IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                APP01030
               WRITE(6,9008)SC                                              APP01040
            GO TO 86                                                        APP01050
   84       CONTINUE                                                        APP01060
            IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                APP01070
               WRITE(6,9009)SC                                              APP01080
            GO TO 86                                                        APP01090
   85       CONTINUE                                                        APP01100
               WRITE(6,9010)                                                APP01110
   86       CONTINUE                                                        APP01120
            WRITE(6,9011)PE,V,N,QS,PD,RJ,KT,KQ,ETAC,R75R,DIA,PDIVD,         APP01130
     1                   AEDVAO,TC75R                                       APP01140
            WRITE(6,9012)DIALIM,AEAOMN,TC75MN                               APP01150
    3  CONTINUE                                                             APP01160
       RETURN                                                               APP01170
C                                                                           APP01180
CCC    MISCELLANEOUS FORMAT STATEMENTS                                      APP01190
C                                                                           APP01200
 9000 FORMAT('1','OPTIMIZATION RESULTS ------- DESIGN CASE NO. ',I3,/,      APP01210
     1       1X,'                          SUBROUTINE "STRCNA"',///)      APP01220
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  PE,V,AEDVAO,DIA,TC75R',//)    APP01230
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',      APP01240
     1       F10.4,/,                                                       APP01250
     1       1X,29X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,               APP01260
     2       1X,29X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                  APP01270
     3       1X,29X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,           APP01280
     4       1X,29X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,///)        APP01290
 9003 FORMAT(1X,'HULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,     APP01300
     1       1X,29X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,             APP01310
     2       1X,29X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,          APP01320
     3       1X,29X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                 APP01330
     4       1X,29X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,        APP01340
     5       1X,29X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,///)                APP01350
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',16X,'=',      APP01360
     1       F10.1)                                                         APP01370
 9005 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                   APP01380
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)              APP01390
 9006 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                  APP01400
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)              APP01410
 9007 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  BRONZE',/,                      APP01420
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)              APP01430
 9008 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                APP01440
```

```
     1        1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP01450
9009 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                  APP01460
     1        1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP01470
9010 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',/)                   APP01480
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,               APP01490
     2        1X,25X,'V  (FT/SEC)',23X,'=',F10.4,/,                            APP01500
     3        1X,25X,'N  (RPM)   ',23X,'=',F10.4,/,                            APP01510
     4        1X,25X,'QS (FT-LBF)',23X,'=',F12.1,/,                            APP01520
     4        1X,25X,'PD  (HP)   ',23X,'=',F10.2,//,                           APP01530
     4        1X,25X,'J          ',23X,'=',F10.4,/,                            APP01540
     4        1X,25X,'KT         ',23X,'=',F10.4,/,                            APP01550
     4        1X,25X,'KQ         ',23X,'=',F10.4,/,                            APP01560
     4        1X,25X,'ETAC       ',23X,'=',F10.4,/,                            APP01570
     5        1X,25X,'REY75R     ',23X,'=',E10.1,/,                            APP01580
     6        1X,25X,'DIA (FT)   ',23X,'=',F10.4,/,                            APP01590
     7        1X,25X,'P/D        ',23X,'=',F10.4,/,                            APP01600
     9        1X,25X,'AE/AO      ',23X,'=',F10.4,/,                            APP01610
     8        1X,25X,'T/C  .75R  ',23X,'=',F10.4,//)                           APP01620
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,         APP01630
     1        1X,25X,'MIN AE/AO',25X,'=',F10.4,/,                              APP01640
     2        1X,25X,'MIN T/C .75R',22X,'=',F10.6)                             APP01650
      END                                                                       APP01660
```

```
      SUBROUTINE ANALIZ(ICALC)                                          APP01690
      INTEGER*4 ICALC                                                   APP01700
      REAL*4 ETAO,WEIGHT,AEDVAO,DIA,N,PE,FDIVD,QS,TC75R,V,              APP01710
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP01720
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                            APP01730
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NGSCRW,HCL,PATM,               APP01740
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP01750
     5       C75R,R75R,KT,KQ,PD                                         APP01760
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,FDIVD,QS,TC75R,V,RJCNL,APP01770
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,    APP01780
     2AEAOCV,TCSTRS,RJ                                                  APP01790
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NGSCRW,HCL,PATM,PWATVA, APP01800
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP01810
C                                                                       APP01820
C     THIS SUBROUTINE, COUPLED WITH CUPES/COMMIN, CONSTITUTES ANALYSIS  APP01830
C     METHOD FOR "DESIGN CASE 1" PROPELLER SELECTION PROBLEMS           APP01840
C                                                                       APP01850
C     INPUT-INITIALIZATION PHASE                                        APP01860
C                                                                       APP01870
      PI=3.14159264                                                     APP01880
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                      APP01890
CC                                                                      APP01900
CC          SET "DESIGN CASE 1" PARAMETERS                              APP01910
CC                                                                      APP01920
CC          ENVIRONMENTAL                                               APP01930
CC                                                                      APP01940
            TEMP=59.0                                                   APP01950
            WATRO=1.9384                                                APP01960
            WATNU=.0000122850                                           APP01970
            PATM=14.7                                                   APP01980
            PWATVA=.247                                                 APP01990
CC                                                                      APP02000
CC          PROPELLER PARAMETERS                                        APP02010
CC                                                                      APP02020
            Z=5.0                                                       APP02030
            PROMAT=5.0                                                  APP02040
CC                                                                      APP02050
CC          HULL PARAMETERS                                             APP02060
CC                                                                      APP02070
            WT=0.22                                                     APP02080
            TC=0.15                                                     APP02090
            ETARR=1.025                                                 APP02100
            NGSCRW=1.0                                                  APP02110
            HCL=19.0                                                    APP02120
            DIALIM=22.0                                                 APP02130
CC                                                                      APP02140
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 1"         APP02150
CC                                                                      APP02160
```

```
            PE=16153.0                                                          APP02170
            VK=24.C                                                             APP02180
            V=1.688*VK                                                          APP02190
            AECVAC=0.85                                                         APP02200
            DIA=22.0                                                            APP02210
            TC75R=((0.0185-0.C0125*Z)*Z)/(2.073*AECVAC)                         APP02220
CC                                                                              APP02230
CC          END OF INPLT-INITIALIZATICN PHASE                                   APP02240
CC                                                                              APP02250
      GO TO 3                                                                   APP02260
C                                                                               APP02270
C     EXECUTICN PHASE                                                           APP02280
C                                                                               APP02290
    1 CONTINUE                                                                  APP02300
      IF(.NOT.(ICALC.EC.2))GC TO 2                                              APP02310
            CALL RNCAL(N)                                                       APP02320
            CALL CF75RA(C75R)                                                   APP02330
            CALL REY75R(C75R,R75R)                                              APP02340
            CALL CCEFSA(RJ,R75R,KT,KQ)                                          APP02350
            CALL OFWEFF(RJ,KT,KQ,ETAO)                                          APP02360
            CALL CALCCS(KC,QS)                                                  APP02370
            CALL JCNA(RJ,RJCNL,RJCNU)                                           APP02380
            CALL REYCNA(R75R,R75RCL,R75RCU)                                     APP02390
            CALL EXTCCN(Z,AECVAC,TC75R,AEACCL,AEACCU,TC75CL,TC75CU)             APP02400
            CALL BLPOW1(KT,POWBAL)                                              APP02410
            CALL DICNUA(DIACNL)                                                 APP02420
            CALL CAVCNA(KT,AEACCV)                                              APP02430
            CALL STRCNK(KC,KT,C75R,TCSTRS)                                      APP02440
CC                                                                              APP02450
CC          END OF EXECUTION PHASE                                              APP02460
CC                                                                              APP02470
      GO TO 3                                                                   APP02480
    2 CONTINUE                                                                  APP02490
C                                                                               APP02500
C     OUTPUT-RESULT PHASE                                                       APP02510
C                                                                               APP02520
            PC=(2.C*PII*QS*N)/33000.0                                           APP02530
            WRITE(6,9000)                                                       APP02540
            WRITE(6,9001)                                                       APP02550
            WRITE(6,9002)TEMP,WATRO,WATNU,PATM,PWATVA                           APP02560
            WRITE(6,9003)WT,TD,ETARR,NOSCRW,HCL,DIALIM                          APP02570
            WRITE(6,9004)Z                                                      APP02580
            IF(.NOT.(PROMAT.EC.1.C))GO TO 81                                    APP02590
                WRITE(6,9005)SC                                                 APP02600
            GC TO 86                                                            APP02610
   81       CONTINUE                                                            APP02620
            IF(.NCT.(PROMAT.EC.2.0))GC TO 82                                    APP02630
                WRITE(6,9006)SC                                                 APP02640
```

```
            GO TO 86                                                        APP02650
   82       CONTINUE                                                        APP02660
            IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                                APP02670
               WRITE(6,9007)SC                                              APP02680
            GO TO 86                                                        APP02690
   83       CONTINUE                                                        APP02700
            IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                APP02710
               WRITE(6,9008)SC                                              APP02720
            GO TO 86                                                        APP02730
   84       CONTINUE                                                        APP02740
            IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                APP02750
               WRITE(6,9009)SC                                              APP02760
            GO TO 86                                                        APP02770
   85       CONTINUE                                                        APP02780
               WRITE(6,9010)                                                APP02790
   86       CONTINUE                                                        APP02800
            WRITE(6,9011)PE,V,N,WS,PD,RJ,KT,KQ,ETAC,R75R,DIA,PDIVD,         APP02810
     1                   AEDVAC,TC75R                                       APP02820
            WRITE(6,9012)DIALIM,AEAOMN,TC75MN                               APP02830
    3  CONTINUE                                                             APP02840
      RETURN                                                                APP02850
C                                                                           APP02860
CC     MISCELLANEOUS FORMAT STATEMENTS                                      APP02870
C                                                                           APP02880
 9000 FORMAT('1','OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1',/,        APP02890
     1       1X,'                                SUBROUTINE "STRCNK"',//)   APP02900
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  PE,V,AEDVAC,DIA,TC75R',//)    APP02910
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',       APP02920
     1       F10.4,/,                                                       APP02930
     1       1X,29X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,               APP02940
     2       1X,29X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                  APP02950
     3       1X,29X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,           APP02960
     4       1X,29X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,//)         APP02970
 9003 FORMAT(1X,'FULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,     APP02980
     1       1X,29X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,             APP02990
     2       1X,29X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,          APP03000
     3       1X,29X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                 APP03010
     4       1X,29X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,        APP03020
     5       1X,29X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,//)                 APP03030
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',      APP03040
     1       F10.1)                                                         APP03050
 9005 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                   APP03060
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)               APP03070
 9006 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                  APP03080
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)               APP03090
 9007 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  BRONZE',/,                      APP03100
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)               APP03110
 9008 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                APP03120
```

```
     1        1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APPO3130
9009 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                  APPO3140
     1        1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APPO3150
9010 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',//)                  APPO3160
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,               APPO3170
     2        1X,29X,'V  (FT/SEC)',23X,'=',F10.4,/,                            APPO3180
     3        1X,29X,'N  (RPM)',23X,'=',F10.4,/,                               APPO3190
     4        1X,29X,'CS (FT-LBF)',23X,'=',F12.1,/,                            APPO3200
     4        1X,29X,'PD  (HP)',23X,'=',F10.2,//,                              APPO3210
     4        1X,29X,'J',23X,'=',F10.4,/,                                      APPO3220
     4        1X,29X,'KT',23X,'=',F10.4,/,                                     APPO3230
     4        1X,29X,'KQ',23X,'=',F10.4,/,                                     APPO3240
     4        1X,29X,'ETAC',23X,'=',F10.4,/,                                   APPO3250
     5        1X,29X,'REY75R',23X,'=',E10.1,/,                                 APPO3260
     6        1X,29X,'DIA (FT)',23X,'=',F10.4,/,                               APPO3270
     7        1X,29X,'P/D',23X,'=',F10.4,/,                                    APPO3280
     9        1X,29X,'AE/AC',23X,'=',F10.4,/,                                  APPO3290
     8        1X,29X,'T/C .75R',23X,'=',F10.4,//)                              APPO3300
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,         APPO3310
     1        1X,29X,'MIN AE/AC',25X,'=',F10.4,/,                              APPO3320
     2        1X,29X,'MIN T/C .75R',22X,'=',F10.6)                             APPO3330
      END                                                                       APPO3340
```

```
      SUBROUTINE ANALIZ(ICALC)                                          APP03370
      INTEGER*4 ICALC                                                   APP03380
      REAL*4 ETAG,WEIGHT,AEDVAD,DIA,N,PE,FDIVD,QS,TC75R,V,              APP03390
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP03400
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                            APP03410
     3       VK,TD,WT,Z,WATRC,WATNU,TEMP,NCSCRW,HCL,PATM,               APP03420
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP03430
     5       C75R,R75R,KT,KC,PD                                         APP03440
      COMMON /GLOBCM/ETAG,WEIGHT,AEDVAD,DIA,N,PE,FDIVD,QS,TC75R,V,RJCNL,APP03450
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,    APP03460
     2AEACCV,TCSTRS,RJ                                                  APP03470
      COMMON /PARAM/VK,TD,WT,Z,WATRD,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA, APP03480
     1PRCMAT,DIALIM,ETARR,AEACMN,TC75MN,SC                              APP03490
C                                                                       APP03500
CC    THIS SUBROUTINE, COUPLED WITH COPES/CONMIN, CONSTITUTES ANALYSIS  APP03510
C     METHOD FOR "DESIGN CASE 1" PROPELLER SELECTION PROBLEMS           APP03520
C                                                                       APP03530
C     INPUT-INITIALIZATION PHASE                                        APP03540
C                                                                       APP03550
      PII=3.14159264                                                    APP03560
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                      APP03570
CC                                                                      APP03580
CC          SET "DESIGN CASE 1" PARAMETERS                              APP03590
CC                                                                      APP03600
CC          ENVIRONMENTAL                                               APP03610
CC                                                                      APP03620
            TEMP=59.0                                                   APP03630
            WATRC=1.9384                                                APP03640
            WATNU=.000012285                                            APP03650
            PATM=14.7                                                   APP03660
            PWATVA=.247                                                 APP03670
CC                                                                      APP03680
CC          PROPELLER PARAMETERS                                        APP03690
CC                                                                      APP03700
            Z=5.0                                                       APP03710
            PRCMAT=5.0                                                  APP03720
CC                                                                      APP03730
CC          HULL PARAMETERS                                             APP03740
CC                                                                      APP03750
            WT=0.22                                                     APP03760
            TC=0.15                                                     APP03770
            ETARR=1.025                                                 APP03780
            NCSCRW=1.0                                                  APP03790
            HCL=19.0                                                    APP03800
            DIALIM=22.0                                                 APP03810
CC                                                                      APP03820
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 1"         APP03830
CC                                                                      APP03840
```

```
      PE=1815.0                                                          APP03850
      VK=24.C                                                            APP03860
      V=1.688*VK                                                         APP03870
CC                                                                       APP03880
CC          END OF INPUT-INITIALIZATION PHASE                            APP03890
CC                                                                       APP03900
      GO TO 3                                                            APP03910
C                                                                        APP03920
C     EXECUTION PHASE                                                    APP03930
C                                                                        APP03940
    1 CONTINUE                                                           APP03950
      IF(.NOT.(ICALC.EQ.2))GO TO 2                                       APP03960
          CALL RNCAL(N)                                                  APP03970
          CALL CF75RA(C75R)                                              APP03980
          CALL REY75R(C75R,R75R)                                         APP03990
          CALL CCEFSA(RJ,R75R,KT,KQ)                                     APP04000
          CALL OPWEFF(RJ,KT,KQ,ETAO)                                     APP04010
          CALL CALCQS(KC,QS)                                             APP04020
          CALL JCNA(RJ,RJCNL,RJCNU)                                      APP04030
          CALL REYCNA(R75R,R75RCL,R75RCU)                                APP04040
          CALL EXTCCN(Z,AELVAC,TC75R,AEACCL,AEACCU,TC75CL,TC75CU)        APP04050
          CALL BLPOW1(KT,POWBAL)                                         APP04060
          CALL DJCNUA(DIACNU)                                            APP04070
          CALL CAVCNA(KT,AEACCV)                                         APP04080
          CALL STRCNA(KC,C75R,TCSTRS)                                    APP04090
CC                                                                       APP04100
CC          END OF EXECUTION PHASE                                       APP04110
CC                                                                       APP04120
      GO TO 3                                                            APP04130
    2 CONTINUE                                                           APP04140
C                                                                        APP04150
CC    OUTPUT-RESULT PHASE                                                APP04160
C                                                                        APP04170
          PD=(2.C*PI1*QS*N)/33000.0                                      APP04180
          WRITE(6,9000)                                                  APP04190
          WRITE(6,9001)                                                  APP04200
          WRITE(6,9002)TEMP,WATRO,WATNU,PATM,PWATVA                      APP04210
          WRITE(6,9003)WT,TD,ETAKR,NUSCRW,HCL,DIALIM                     APP04220
          WRITE(6,9004)Z                                                 APP04230
          IF(.NOT.(PROMAT.EQ.1.0))GO TO 81                               APP04240
              WRITE(6,9005)SC                                            APP04250
          GO TO 86                                                       APP04260
   81     CONTINUE                                                       APP04270
          IF(.NOT.(PROMAT.EQ.2.0))GO TO 82                               APP04280
              WRITE(6,9006)SC                                            APP04290
          GO TO 86                                                       APP04300
   82     CONTINUE                                                       APP04310
          IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                               APP04320
```

```
            WRITE(6,9007)SC                                                     APP04330
          GO TO 86                                                              APP04340
   83     CONTINUE                                                              APP04350
          IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                      APP04360
            WRITE(6,9008)SC                                                     APP04370
          GO TO 86                                                              APP04380
   84     CONTINUE                                                              APP04390
          IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                      APP04400
            WRITE(6,9009)SC                                                     APP04410
          GO TO 86                                                              APP04420
   85     CONTINUE                                                              APP04430
            WRITE(6,9010)                                                       APP04440
   86     CONTINUE                                                              APP04450
          WRITE(6,9011)PE,V,N,DS,PD,AJ,KT,KQ,ETAC,R75R,DIA,PDIVD,               APP04460
     1                 AEDVAC,TC75R                                           APP04470
          WRITE(6,9012)DIALIM,AEADMN,TC75MN                                     APP04480
    3 CONTINUE                                                                  APP04490
      RETURN                                                                    APP04500
C                                                                               APP04510
CC     MISCELLANEOUS FORMAT STATEMENTS                                          APP04520
C                                                                               APP04530
 9000 FORMAT('1','OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1',/             APP04540
     1       1X,'                                SUBROUTINE "STRCNA"',///)      APP04550
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  PE,V',/)                          APP04560
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',           APP04570
     1       F10.4,/,                                                           APP04580
     1       1X,25X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,                   APP04590
     2       1X,25X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                      APP04600
     3       1X,25X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,               APP04610
     4       1X,25X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,///)            APP04620
 9003 FORMAT(1X,'HULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,         APP04630
     1       1X,25X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,                 APP04640
     2       1X,25X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,              APP04650
     3       1X,25X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                     APP04660
     4       1X,25X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,            APP04670
     5       1X,25X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,///)                    APP04680
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',          APP04690
     1       F10.1)                                                             APP04700
 9005 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                       APP04710
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP04720
 9006 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                      APP04730
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP04740
 9007 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  BRONZE',/,                          APP04750
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP04760
 9008 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                    APP04770
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP04780
 9009 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                 APP04790
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP04800
```

```
9010 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',/)                    APPC4610
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,                APPC4620
     2      1X,25X,'V   (FT/SEC)',23X,'=',F10.4,/,                              APPC4630
     3      1X,25X,'N   (RPM)',23X,'=',F10.4,/,                                 APPC4640
     4      1X,25X,'CS  (FT-LBF)',23X,'=',F12.1,/,                              APPC4650
     4      1X,25X,'PD  (HP)',23X,'=',F10.2,//,                                 APPC4660
     4      1X,25X,'J',23X,'=',F10.4,/,                                         APPC4670
     4      1X,25X,'KT',23X,'=',F10.4,/,                                        APPC4680
     4      1X,25X,'KQ',23X,'=',F10.4,/,                                        APPC4690
     4      1X,25X,'ETAO',23X,'=',F10.4,/,                                      APPC4700
     5      1X,25X,'REY75R',23X,'=',E10.1,/,                                    APPC4710
     6      1X,25X,'DIA (FT)',23X,'=',F10.4,/,                                  APPC4720
     7      1X,25X,'P/D',23X,'=',F10.4,/,                                       APPC4730
     9      1X,25X,'AE/AC',23X,'=',F10.4,/,                                     APPC4740
     8      1X,25X,'T/C .75R',23X,'=',F10.4,///)                                APPC4750
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,          APPC4760
     1      1X,25X,'MIN AE/AC',25X,'=',F10.4,/,                                 APPC4770
     2      1X,25X,'MIN T/C .75R',22X,'=',F10.6)                                APPC4780
      END                                                                       APPC4790
```

```
      SUBROUTINE ANALIZ(ICALC)                                          APP05020
      INTEGER*4 ICALC                                                   APP05030
      REAL*4 ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,              APP05040
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP05050
     2       FCWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                            APP05060
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,               APP05070
     4       PWATVA,PRCMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP05080
     5       C75R,R75R,KT,KC,PD                                         APP05090
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP05100
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,FCWBAL,DIACNU,    APP05110
     2AEACCV,TCSTRS,RJ                                                  APP05120
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA, APP05130
     1PRCMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP05140
                                                                        APP05150
C     THIS SUBROUTINE, COUPLED WITH COPES/CONMIN, CONSTITUTES ANALYSIS  APP05160
C     METHOD FOR "DESIGN CASE 1" PROPELLER SELECTION PROBLEMS           APP05170
C                                                                       APP05180
C     INPUT-INITIALIZATION PHASE                                        APP05190
C                                                                       APP05200
      PII=3.14159264                                                    APP05210
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                      APP05220
C                                                                      *APP05230
CC          SET "DESIGN CASE 1" PARAMETERS                            APP05240
CC                                                                    APP05250
CC          ENVIRONMENTAL                                             APP05260
CC                                                                    APP05270
            TEMP=59.0                                                 APP05280
            WATRO=1.9384                                              APP05290
            WATNU=.000012285                                          APP05300
            PATM=14.7                                                 APP05310
            PWATVA=.247                                               APP05320
CC                                                                    APP05330
CC          PROPELLER PARAMETERS                                      APP05340
CC                                                                    APP05350
            Z=5.0                                                     APP05360
            PRCMAT=5.0                                                APP05370
CC                                                                    APP05380
CC          HULL PARAMETERS                                           APP05390
CC                                                                    APP05400
            WT=0.22                                                   APP05410
            TC=0.15                                                   APP05420
            ETARR=1.025                                               APP05430
            NCSCRW=1.0                                                APP05440
            HCL=19.0                                                  APP05450
            DIALIM=22.0                                               APP05460
CC                                                                    APP05470
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 1"       APP05480
CC                                                                    APP05490
```

```
      PE=18153.0                                                        APP05500
      VK=24.C                                                           APP05510
      V=1.68E*VK                                                        APP05520
CC                                                                      APP05530
CC          END OF INPUT-INITIALIZATION PHASE                           APP05540
CC                                                                      APP05550
      GO TO 3                                                           APP05560
C                                                                       APP05570
C     EXECUTION PHASE                                                   APP05580
C                                                                       APP05590
    1 CONTINUE                                                          APP05600
      IF(.NOT.(ICALC.EQ.2))GO TO 2                                      APP05610
      CALL RNCAL(N)                                                     APP05620
      CALL C75RA(C75R)                                                  APP05630
      CALL REY75R(C75R,R75R)                                            APP05640
      CALL CCEFSA(RJ,R75R,KT,KQ)                                        APP05650
      CALL OPWEFF(RJ,KT,KQ,ETAO)                                        APP05660
      CALL CALCQS(KQ,QS)                                                APP05670
      CALL JCNA(RJ,RJCNL,KJCNU)                                         APP05680
      CALL REYCNA(R75R,R75RCL,R75RCU)                                   APP05690
      CALL EXTCCN(Z,AEDVAD,TC75R,AEACCL,AEACCU,TC75CL,TC75CU)           APP05700
      CALL BLPOW1(KT,PCWBAL)                                            APP05710
      CALL DICNUA(DIACNU)                                               APP05720
      CALL CAVCNA(KT,AEACCV)                                            APP05730
      CALL STRCNK(KQ,KT,C75R,TCSTRS)                                    APP05740
CC                                                                      APP05750
CC          END OF EXECUTION PHASE                                      APP05760
CC                                                                      APP05770
      GO TO 3                                                           APP05780
    2 CONTINUE                                                          APP05790
C                                                                       APP05800
CC    OUTPUT-RESULT PHASE                                               APP05810
C                                                                       APP05820
      PC=(2.C*PII*QS*N)/33000.0                                         APP05830
      WRITE(6,9000)                                                     APP05840
      WRITE(6,9001)                                                     APP05850
      WRITE(6,9002)TEMP,WATRO,WATNU,PATM,PWATVA                         APP05860
      WRITE(6,9003)WT,TD,ETARR,MLSCRW,HCL,DIALIM                        APP05870
      WRITE(6,9004)Z                                                    APP05880
      IF(.NOT.(PROMAT.EQ.1.0))GO TO 81                                  APP05890
        WRITE(6,9005)SC                                                 APP05900
      GO TO 86                                                          APP05910
   81 CONTINUE                                                          APP05920
      IF(.NOT.(PROMAT.EQ.2.C))GO TO 82                                  APP05930
        WRITE(6,9006)SC                                                 APP05940
      GO TO 86                                                          APP05950
   82 CONTINUE                                                          APP05960
      IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                                  APP05970
```

```
                WRITE(6,9007)SC                                                 APPC5980
          GO TO 86                                                              APPC5990
   83     CONTINUE                                                              APP06000
          IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                      APP06010
                WRITE(6,9008)SC                                                 APP06020
          GO TO 86                                                              APP06030
   84     CONTINUE                                                              APP06040
          IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                      APP06050
                WRITE(6,9009)SC                                                 APP06060
          GO TO 86                                                              APP06070
   85     CONTINUE                                                              APP06080
                WRITE(6,9010)                                                   APP06090
   86     CONTINUE                                                              APP06100
          WRITE(6,9011)PE,V,N,DS,PD,RJ,KT,KQ,ETAC,R75R,DIA,PDIVD,               APP06110
     1                 AEDVAO,TC75R                                           APP06120
          WRITE(6,9012)DIALIM,AEAOMN,TC75MN                                     APP06130
    3 CONTINUE                                                                  APP06140
      RETURN                                                                    APP06150
C                                                                               APP06160
CC    MISCELLANEOUS FORMAT STATEMENTS                                           APP06170
C                                                                               APP06180
 9000 FORMAT('1','OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1',/             APP06190
     1       1X,'                                SUBROUTINE "STRCNK"',//)       APP06200
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  PE,V',/)                          APP06210
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',           APP06220
     1       F10.4,/,                                                           APP06230
     1       1X,29X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,                   APP06240
     2       1X,29X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                      APP06250
     3       1X,29X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,               APP06260
     4       1X,29X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,//)             APP06270
 9003 FORMAT(1X,'HULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,         APP06280
     1       1X,29X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,                 APP06290
     2       1X,29X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,              APP06300
     3       1X,29X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                     APP06310
     4       1X,29X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,            APP06320
     5       1X,29X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,//)                     APP06330
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',          APP06340
     1       F10.1)                                                             APP06350
 9005 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                       APP06360
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)                  APP06370
 9006 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                      APP06380
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)                  APP06390
 9007 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  BRONZE',/,                          APP06400
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)                  APP06410
 9008 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                    APP06420
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)                  APP06430
 9009 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                 APP06440
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)                  APP06450
```

```
 9010 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',//)                  APP06460
 9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,               APP06470
     2       1X,25X,'V   (FT/SEC)',23X,'=',F10.4,/,                             APP06480
     3       1X,25X,'N   (RPM)',23X,'=',F10.4,/,                                APP06490
     4       1X,25X,'QS  (FT-LBF)',23X,'=',F12.1,/,                             APP06500
     4       1X,25X,'PD  (HP)',23X,'=',F10.2,//,                                APP06510
     4       1X,25X,'J',23X,'=',F10.4,/,                                        APP06520
     4       1X,25X,'KT',23X,'=',F10.4,/,                                       APP06530
     4       1X,25X,'KQ',23X,'=',F10.4,/,                                       APP06540
     4       1X,25X,'ETAO',23X,'=',F10.4,/,                                     APP06550
     5       1X,25X,'REY75R',23X,'=',E10.1,/,                                   APP06560
     6       1X,25X,'DIA (FT)',23X,'=',F10.4,/,                                 APP06570
     7       1X,25X,'P/D',23X,'=',F10.4,/,                                      APP06580
     9       1X,25X,'AE/AO',23X,'=',F10.4,/,                                    APP06590
     8       1X,25X,'T/C .75R',23X,'=',F10.4,//)                                APP06600
 9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,        APP06610
     1       1X,25X,'MIN AE/AO',25X,'=',F10.4,/,                                APP06620
     2       1X,25X,'MIN T/C .75R',22X,'=',F10.6)                               APP06630
       END                                                                      APP06640
```

CONTROL CARD IMAGES--DESIGN CASE NO. 1

```
$A   TITLE
   WAGENINGEN E-SERIES PROPELLER OPTIMIZATION
$B    NCALC      NDV      NSV     N2VAR     NXAPRX     IPNPUT      IPDBG
          2        2                                        0
$C   IPRINT     ITMAX    ICNDIR    NSCAL      ITRM    LINOBJ     NACMX1
          1     1000                -1                             15
$D1    FDCH     FDCHM       CT     CTMIN       CTL    CTLMIN     THETA
     0.0001    0.0001
$D2  CELFUN    CABFUN    ALPHAX    ABOBJ1
$E    NDVTOT     ICBJ    SGNOPT
          2        1       1.0
$F       VLB      VUB         X      SCAL
         0.01      1.8       0.1       1.0
          0.4      1.4       0.5       1.0
$G    NDSSGN    IDSGN     AMULT
          1       23       1.0
          2        7       1.0
$H    NCONS
          5
$I1    ICON      JCON      LCON
$I2      BL     SCAL1        BU     SCAL2
          11        11
-1.0    +16       1.0       0.0       1.0
          12        12
-1.0    +16       1.0       0.0       1.0
          13        13
-1.0    +16       1.0       0.0       1.0
          14        14
-1.0    +16       1.0       0.0       1.0
          15        15
-1.0    +16       1.0       0.0       1.0
          16        16
-1.0    +16       1.0       0.0       1.0
          17        17
-1.0    +16       1.0       0.0       1.0
          18        18
-1.0    +16       1.0       0.0       1.0
          19        19
-1.0    +16       1.0       0.0       1.0
$V
END
```

```
$A   TITLE
  WAGENINGEN E-SERIES PROPELLER OPTIMIZATION
$B    NCALC      NDV      NSV     N2VAR     NXAPRX     IPNPUT     IPDBG
          2        5                                         0
$C   IPRINT     ITMAX    ICNDIR     NSCAL     ITRM     LINOBJ     NACMXI
          1     1000                  -1       30                   15
$D1     FDCH     FDCHM       CT     CTMIN      CTL     CTLMIN    THETA
     0.0001    0.0001
$D2  CELFUN     CABFUN    ALPHAX     ABOBJI

$E   NDVTOT       IOBJ     SGNOPT
          5          1        1.0
$F       VLB        VUB          X       SCAL
         0.2        1.1        0.30       1.0
         1.0      50.0        30.0       10.0
        0.01        1.6         0.1        1.0
         0.4        1.4         0.5        1.0
       0.003        0.5      0.0300      0.010
$G   NDSSGN     IDSGN     AMULT
          1         3       1.0
          2         4       1.0
          3        23       1.0
          4         7       1.0
          5         9       1.0
$H    NCONS
         12
$I1     ICON      JCON      LCON
$I2       BL     SCAL1        BU      SCAL2
         11        11
-1.0    +16       1.0       0.0       1.0
         12        12
-1.0    +16       1.0       0.0       1.0
         13        13
-1.0    +16       1.0       0.0       1.0
         14        14
-1.0    +16       1.0       0.0       1.0
         15        15
-1.0    +16       1.0       0.0       1.0
         16        16
-1.0    +16       1.0       0.0       1.0
         17        17
-1.0    +16       1.0       0.0       1.0
         18        18
-1.0    +16       1.0       0.0       1.0
         19        19
-1.0    +16       1.0       0.0       1.0
         20        20
-1.0    +16       1.0       0.0       1.0
```

```
                21              21
-1.0     +16    1.0      0.0    1.0
                22              22
-1.0     +16    1.0      0.0    1.0
$V
END
```

APPENDIX E

COPES OUTPUT--DESIGN CASE NO. 1

CARD IMAGES OF CONTROL DATA

```
CARD                    IMAGE

  1  $A  TITLE
  2      WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
  3  $E    ACALC       NCV       NSV      N2VAR    MAXPRX     IPNPLT     IPUBU
  4              2         2                                       0
  5  $C   IFKIN1     ITMAX    ICRUIS     NSCAL      IIKM    LINUEJ    NACMX1
  6              1      1300                -1                            15
  7  $E1     FDCH     FDCHM        CT    CTMIN      CTL    CTLMIN     THETA
  8     0.0001    0.0001
  9  $E2 DELFUN    DABFLN    ALFMAX    ABCEJI
 10
100
101  $F  AEWTOT      IOBJ    SGRCPT
102              2         1       1.0
103  $F      VLB       VUB         X      SCAL
104          0.01       1.8       0.1       1.0
105           0.4       1.4       0.3       1.0
106  $E  NESSGN     JDSGN     APWLT
107              1        43       1.0
108              2         7       1.0
109  $F   ACONS
200              8
201  $II    ICON      JCON      ICON
202  $I2      01     SCALI1        BU     SCALZ
203              1        11
204  -1.0    +1.0       1.0       0.0       1.0
205              2        12
206  -1.0    +1.0       1.0       0.0       1.0
207              3        13
208  -1.0    +1.0       1.0       0.0       1.0
209              4        14
210  -1.0    +1.0       1.0       0.0       1.0
211              5        15
212  -1.0    +1.0       1.0       0.0       1.0
213              6        16
214  -1.0    +1.0       1.0       0.0       1.0
215              7        17
216  -1.0    +1.0       1.0       0.0       1.0
217              8        18
218  -1.0    +1.0       1.0       0.0       1.0
219              9        19
220  -1.0    +1.0       1.0       0.0       1.0
221  $I
222  $E
```

```
TITLE:
  WAGENINGEN B-SERIES PROPELLER OPTIMIZATION


CONTROL PARAMETERS:
CALCULATION CONTROL.                    NCALC =      2
NUMBER OF GLOBAL DESIGN VARIABLES,       NDV =      2
NUMBER OF SENSITIVITY VARIABLES,         NSV =      0
NUMBER OF FUNCTIONS IN TLG-SPACE,       N2VAR =      0
NUMBER OF APPROXIMATION VAR.            NZAPRX =      0
INPUT INFORMATION PRINT CODE.            IPRINT =      0
DEBUG PRINT CODE.                        IDEBG =      0

CALCULATION CONTROL, NCALC
VALUE    MEANING
  1      SINGLE ANALYSIS
  2      OPTIMIZATION
  3      SENSITIVITY
  4      TLG-VARIABLE FUNCTION SPACE
  5      OPTIMUM SENSITIVITY
  6      APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE                    =      1
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION)           =  0.10000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT      ITMAX      ICNCIR      NSCAL      ITRM      LINOBJ      NACMXI      MFDG
     1      ICCO           0         -1         0           0          15         0

FDCH                   FDCHM                  CT                     CTMIN
0.10000E-03            0.10000E-03            0.0                    0.0

CTL                    CTLMIN                 THETA                  PHI
0.0                    0.0                    0.0                    0.0

DELFUN                 DABFUN                 ALPHAX                 ABOBJ1
0.0                    0.0                    0.0                    0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
G. V.      LOWER                  UPPER                  INITIAL
NO.        BOUND                  BOUND                  VALUE                  SCALE
  1    0.10000E-01            0.18000E+01            0.10000E+00            0.10000E+01
  2    0.40000E+00            0.14000E+01            0.50000E+00            0.10000E+01

DESIGN VARIABLES
ID      D. V.      GLOBAL      MULTIPLYING
        NO.        VAR. NO.      FACTOR
 1        1            1       0.10000E+01
 2        2            2       0.10000E+01

CONSTRAINT INFORMATION

THERE ARE   0 CONSTRAINT SETS
        GLOBAL   LINEAR
 ID      VAR.     VAR.      ID      LOWER BOUND      NORMALIZATION FACTOR      UPPER BOUND      NORMALIZATION FACTOR
  1        1        1       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  2        2        2       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  3        3        3       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  4        4        4       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  5        5        5       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  6        6        6       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  7        7        7       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  8        8        8       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01
  9        9        9       0     -0.10000E+16      0.10000E+01               0.0              0.10000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS =      9


* * ESTIMATED DATA STORAGE REQUIREMENTS
```

57 450 15000 36. 57. 1000

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1
SUBROUTINE "STRCNA"

DESIGN VARIABLES SPECIFIED: PE,V,AE/AO,DIA,TC75R

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	55.0000
	DENSITY (LBF-SEC**2/FT4)	=	1.9385
	VISCOSITY (FT2/SEC)	=	0.1226499978-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	5.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5430.3
SELECTION VALUES:	PE (HP)	=	18353.0
	V (FT/SEC)	=	40.5120
	N (RPM)	=	861.0003
	DS (FT-LBF)	=	29133144.0
	PD (HP)	=	48466C85.00
	J	=	0.1000
	KT	=	0.1735
	KQ	=	0.0143
	ETAL	=	0.1521
	RETTSR	=	0.5E+09
	DIA (FT)	=	22.0000
	P/D	=	0.5000
	AE/AO	=	0.8530
	T/C .75R	=	0.0348
CONSTRAINT VALUES:	MAX DIA (FT)	=	22.0000
	MIN AE/AO	=	0.7842
	MIN T/C .75R	=	0.019990

```
        C L M I N
    FORTRAN PROGRAM FOR
CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =  -C.152694E+00

DECISION VARIABLES (X-VECTOR)
  1)     C.10000E+00  0.50000E+00

CONSTRAINT VALUES (G-VECTOR)
  1)    -C.62500E-01 -0.93750E+00 -0.23713E+03 -0.76485E+03 -C.40000E+00 -0.20000E+00
  7)    -0.22691E-01 -0.22188E+00 -0.93755E+02
```

```
FINAL OPTIMIZATION INFORMATION

OBJ =  -0.76073E+00

DECISION VARIABLES (X-VECTOR)
 1)    0.73712E+00  0.10003E+01

CONSTRAINT VALUES (G-VECTOR)
 1)   -0.44010E+00 -0.53933E+00 -0.32395E+02 -0.96660E+03 -0.40000E+00 -0.20000E+00
 7)   -0.22691E-01 -0.32788E+00  0.12279E-04

THERE ARE    1 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
     6

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
     ABS(1-OBJ(I-1)/OBJ(I))) LESS THAN DELFUN FOR  3 ITERATIONS
     ABS(OBJ(I)-OBJ(I-1))  LESS THAN DABFUN FOR  3 ITERATIONS

NUMBER OF ITERATIONS =  14

OBJECTIVE FUNCTION WAS EVALUATED          69  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       69  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 1 FUNCTION VALUE 0.70507E+00

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	23	0.10000E-01	0.73712E+00	0.14000E+01
2	2	7	0.40000E+00	0.10036E+01	0.14000E+01

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.11000E+16	-0.34077E+00	0.0
2	12	-0.11000E+16	-0.33934E+00	0.0
3	13	-0.11000E+16	-0.72395E+02	0.0
4	14	-0.11000E+16	-0.56640E+03	0.0
5	15	-0.11000E+16	-0.40026E+00	0.0
6	16	-0.11000E+16	-0.20000E+00	0.0
7	17	-0.11000E+16	-0.27085E-01	0.0
8	18	-0.11000E+16	-0.22708E+00	0.0
9	19	-0.11000E+16	0.12279E-04	0.0

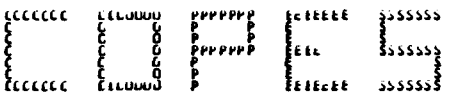
OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1
SUBROUTINE "STANNA"

DESIGN VARIABLES SPECIFIED: PE,V,AECVAC,DIA,TC75R

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	59.0000
	DENSITY (LBF-SEC**2/FT4)	=	1.9384
	VISCOSITY (FT2/SEC)	=	0.12849997E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	2.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	5.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTION VALUES:	PE (HP)	=	16133.0
	V (FT/SEC)	=	42.5120
	N (RPM)	=	116.9142
	QS (FT-LBF)	=	1C80431.0
	PD (HP)	=	24251.2
	J	=	0.7371
	KT	=	0.1262
	KQ	=	0.0285
	ETAC	=	0.7091
	AEAY70R	=	0.3E+08
	DIA (FT)	=	22.0000
	P/C	=	1.0036
	AE/AL	=	0.8500
	T/C .75R	=	0.0348
CONSTRAINT VALUES:	MAX DIA (FT)	=	22.0000
	MIN AE/AO	=	0.5520
	MIN T/C .75R	=	0.021266

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	20
3	2



CENTRAL PROGRAM
FOR
ENGINEERING SYNTHESIS

TITLE
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CARD IPACES OR CONTROL DATA

CARD IMAGE

```
 1| $A  TITLE
 2|    BAGENINGEN B-SERIES PROPELLER OPTIMIZATION
 3| $E    ACALC      NCV       NSV      N2VAR    NXAPRX    IPNPLT    IPDUG
 4|                    2                                        0
 5| $C  IPRINT      ITMAX    ICRUIR     NSCAL      ITRM    CINOBJ    MACMAX
 6|        1         1000                -1                           15
 7| $E1    FUCH     FDCHM        CT     CTMIN       CTL    CTLMIN     THETA
 8|      0.0001    0.0001
 9| $E2 DELFUN     DABFUN    ALPMAX    ABOBJ1
10|
11| $E  ACVTOT      IGEJ    SGNOPT
12|        2          1       1.0                                      15
13| $F     VLB        VUB         X      SCAL
14|       0.01        1.8       0.1       1.0
15|        0.4        1.4       0.5       1.0
16| $E  NLSSQN     IDSGN     APUK
17|        1         23       1.0
18|        2          7       1.0
19| $F    ACONS
20|        3
21|    ICON      JCON      LCON
22| $$$   BL        BU      SCAL1      SCAL2
23| $$$
24| -1.0    +16     1.0       0.0       1.0
25| -1.0    +12     1.0       0.0       1.0
26| -1.0    +16     1.0       0.0       1.0
27| -1.0    +13     1.0       0.0       1.0
28| -1.0    +16     1.0       0.0       1.0
29| -1.0    +14     1.0       0.0       1.0
30| -1.0    +16     1.0       0.0       1.0
31| -1.0    +15     1.0       0.0       1.0
32| -1.0    +16     1.0       0.0       1.0
33| -1.0    +16     1.0       0.0       1.0
34| -1.0    +16     1.0       0.0       1.0
35| -1.0    +17     1.0       0.0       1.0
36| -1.0    +16     1.0       0.0       1.0
37| -1.0    +18     1.0       0.0       1.0
38| -1.0    +16     1.0       0.0       1.0
39| -1.0    +19     1.0       0.0       1.0
40| -1.0    +16     1.0       0.0       1.0
41| $D
42| EOC
```

TITLE:
MACEMATICA M-SERIES PROPELLER OPTIMIZATION

CONTROL PARAMETERS
CALCULATION CONTROL, NCALC = 2
NUMBER OF GLOBAL DESIGN VARIABLES, NDV = 2
NUMBER OF SENSITIVITY VARIABLES, NSV = 0
NUMBER OF FUNCTIONS IN T.O-SPACE, NZVAR = 0
NUMBER OF APPROXIMATION VAR, NXAPRX = 0
INPUT APPROPRIATION PRINT CODE, IPRINT = 0
DEBUG PRINT CODE, IPDBG = 0

CALCULATION CONTROL, NCALC
VALUE MEANING
1 SINGLE ANALYSIS
2 OPTIMIZATION
3 SENSITIVITY
4 SEQ-LINEAR FUNCTION SPACE
5 OPTIMUM SENSITIVITY
6 APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 1
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.10000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNCIR	NSCAL	ITRM	LINOBJ	MACNT1	NFCG
1	1000	0	-1	0	0	15	0

FDCH	FDCHM	CT	CTMIN
0.10000E-02	0.10000E-03	0.0	0.0

CTL	CTLMIN	THETA	PHI
0.0	0.0	0.0	0.0

DELFUN	DABFUN	ALPMAX	ABGOJI
0.0	0.0	0.0	0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LINEAR BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.10000E-01	0.10000E+11	0.10000E+00	0.10000E+01
2	0.14000E+00	0.14222E+11	0.35000E+00	0.10000E+01

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING OBJECTIVE
1	1	23	0.10000E+01
2	2	7	0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 5 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	11	11	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
2	12	12	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00
3	13	13	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00
4	14	14	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00
5	15	15	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00
6	16	16	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00
7	17	17	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00
8	18	18	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00
9	19	19	0	-0.11000E+16	0.10000E+01	0.0	0.33333E+00

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 9

* * ESTIMATED DATA STORAGE REQUIREMENTS

57 450 15000 32 99 1000

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1
SUBROUTINE "STRLNK"

DESIGN VARIABLES SPECIFIED: PE,V,AE/VAC,DIA,TC75R

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	55.0000
	DENSITY (LBF-SEC2/FT4)	=	1.9384
	VISCOSITY (FT2/SEC)	=	0.1284999?E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	5.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTED VALUES:	PE (HP)	=	16154.0
	V (FT/SEC)	=	42.5120
	N (RPM)	=	661.8033
	QS (FT-LBF)	=	29333744.0
	PD (HP)	=	48466?85.00
	J	=	0.1000
	KT	=	0.1735
	KQ	=	0.0143
	ETAC	=	0.1927
	REY75R	=	0.5E+09
	DIA (FT)	=	22.0000
	P/C	=	0.5000
	AE/AC	=	0.8500
	T/C .75R	=	0.0348
CONSTRAINT VALUES:	MAX DIA (FT)	=	22.0000
	MIN AE/AO	=	26.7882
	MIN T/C .75R	=	0.134720

```
C L P M I N
FORTRAN PROGRAM FOR
CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =  -C.152694E+0C

DECISION VARIABLES (X-VECTOR)
  1)      C.1C000E+00  C.500CCE+00

CONSTRAINT VALUES (G-VECTOR)
  1)    -C.42500E-01 -0.93755E+00 -0.24412E+03 -0.76485E+03 -C.40000E+00 -0.20000E+00
  7)    -0.2C691E-01 -0.22188E+00 -0.13755E+02
```

```
FINAL OPTIMIZATION INFORMATION

OBJ =  -0.269073E+00

DECISION VARIABLES (X-VECTOR)
  1)     0.73112E+00  0.16033E+01

CONSTRAINT VALUES (G-VECTOR)
  1)    -0.54030E+00 -0.53934E+00 -0.32356E+02 -0.96660E+03 -0.40000E+00 -0.20000E+00
  7)    -0.22691E-01 -0.22788E+03  0.12219E-04

THERE ARE    1 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
     6

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
     ABS(1-OBJ(I-1)/OBJ(I)) LESS THAN DELFUN FOR  3 ITERATIONS
     ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR  3 ITERATIONS

NUMBER OF ITERATIONS =   14

OBJECTIVE FUNCTION WAS EVALUATED          69  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       69  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 1 FUNCTION VALUE 0.70907E+00

DESIGN VARIABLES

ID	C. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	23	0.10000E-01	0.73132E+00	0.10000E+01
2	2	7	0.40000E+00	0.10036E+01	0.14000E+01

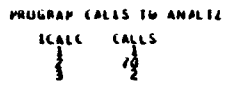
DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.11000E+16	-0.46077E+00	0.0
2	12	-0.11000E+16	-0.53930E+00	0.0
3	13	-0.11000E+16	-0.32395E+02	0.0
4	14	-0.11000E+16	-0.56626E+03	0.0
5	15	-0.11000E+16	-0.60000E+00	0.0
6	16	-0.11000E+16	-0.20316E+00	0.0
7	17	-0.11000E+16	-0.20651E-01	0.0
8	18	-0.11000E+16	-0.22788E+00	0.0
9	19	-0.11000E+16	0.12219E-04	0.0

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1
SUBROUTINE "STRCNR"

DESIGN VARIABLES SPECIFIED: PE,V,AE/VAC,DIA,TC/5R

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	55.0000
	DENSITY (LBF-SEC**2/FT4)	=	1.9384
	VISCOSITY (FT2/SEC)	=	0.122499976-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	5.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTION VALUES:	PE (HP)	=	16154.0
	V (FT/SEC)	=	42.5140
	N (RPM)	=	116.9162
	QS (FT-LBF)	=	1760431.0
	PD (HP)	=	24251.27
	J	=	0.7371
	KT	=	0.1112
	KQ	=	0.0285
	ETAO	=	0.7091
	AE/AO	=	0.7600
	DIA (FT)	=	21.0000
	P/D	=	1.0036
	AE/AC	=	0.8500
	T/C .75R	=	0.0348
CONSTRAINT VALUES:	MAX DIA (FT)	=	22.0000
	MIN AE/AO	=	0.5250
	MIN T/C .75R	=	0.050761


PROGRAM CALLS TO ANALYZ
SCALE
CALLS



CONTROL PROGRAM
FOR
ENGINEERING SYNTHESIS

TITLE
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CARD IMAGES OF CONTROL DATA

```
CARD                    IMAGE

 1| $#  TITLE
 2|   WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
 3| $E     RCALC       NCV         NSV        N2VAR      NXAPRX      IPNPLT      IPUBG
 4|                      5                                                0
 5| $C   IFRIN1      ITMAX      ICNDIR       NSCAL       ITRM      LINDEJ     NALMX1
 6|                    1000          -1          30          1          12
 7| $C1    FDCM       FDCMN         CT       CTMIN        CTL      CTLMIN      THETA
 8|     0.0001      0.0001
 9| $C2 DELFUN     DABFUN     ALFMAX     ABOBJ1
10|
11|
12| $E   NCVTOT       IGEJ     SGNOPT
13|                      5          1        1.0
14| $F       VLB        VLB          X       SCAL
15|              0.2          1.1          0.30        1.0
16|              1.0          5.0          20.0        10.0
17|             0.01          1.6           0.1         1.0
18|              0.4          1.4           0.3         1.0
19|           0.303          2.5         0.0300       0.010
20| $E   NESSGN       IOSGN       APUL
21|                      1           3        1.0
22|                      2           4        1.0
23|                      3           8        1.0
24|                      4           7        1.0
25|                      5           9        1.0
26| $F    ACONS
27|                     12
28| $11     ICON        JCCN        LCON
29| $12       BL       SCAL1          BU      SCAL2
30|                      11          11
31|  -1.0     +16         1.0          12         0.0         1.0
32|  -1.0     +16         1.0          12         0.0         1.0
33|  -1.0     +16         1.0          13         0.0         1.0
34|  -1.0     +16         1.0          14         0.0         1.0
35|  -1.0     +16         1.0          15         0.0         1.0
36|  -1.0     +16         1.0          16         0.0         1.0
37|  -1.0     +16         1.0          17         0.0         1.0
38|  -1.0     +16         1.0          18         0.0         1.0
39|  -1.0     +16         1.0          19         0.0         1.0
40|  -1.0     +16         1.0          20         0.0         1.0
41|  -1.0     +16         1.0          21         0.0         1.0
42|  -1.0     +16         1.0          22         0.0         1.0
43| $$
44| $EC
```

TITLE:
MAGENTAGEN B-SERIES PROPELLER OPTIMIZATION

CONTROL PARAMETERS:

CALCULATION CONTROL,	NCALC =	6
NUMBER OF GLOBAL DESIGN VARIABLES,	NDV =	5
NUMBER OF SENSITIVITY VARIABLES,	NSV =	0
NUMBER OF FUNCTIONS IN TWO-SPACE,	N2VAR =	0
NUMBER OF APPROXIMATION VAR.	NXAPRX =	0
INPUT INFORMATION PRINT CODE,	IPRINT =	0
DEBUG PRINT CODE.	IPDBG =	0

CALCULATION CONTROL, NCALC

VALUE	MEANING
1	SINGLE ANALYSIS
2	OPTIMIZATION
3	SENSITIVITY
4	NON-VARIABLE FUNCTION SPACE
5	OPTIMUM SENSITIVITY
6	APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 1
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.10000E+01

COMMIN PARAMETERS (IF ZERO, COMMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	IERR	LINOBJ	NACMXI	NFDG
1	100	0	-1	30	0	15	0

FDCH	FDCHM	CT	CTMIN
0.10000E-03	0.10000E-03	0.0	0.0

CTL	CTLMIN	THETA	PHI
0.0	0.0	0.0	0.0

DELFUN	DABFUN	ALPHAX	ABOBJ1
0.0	0.0	0.0	0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.10000E+00	0.11000E+01	0.30000E+00	0.10000E+01
2	0.10000E+01	0.50000E+02	0.30000E+02	0.10000E+01
3	0.0	0.10000E+00	0.10000E+00	0.10000E+01
4	0.10000E+00	0.40000E+01	0.30000E+00	0.10000E+01
5	0.30000E-02	0.50000E+00	0.30000E-01	0.10000E-01

DESIGN VARIABLES

IV	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	3	0.10000E+01
2	2	4	0.10000E+01
3	3	23	0.10000E+01
4	4	7	0.10000E+01
5	5	9	0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 12 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	11	11	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
2	12	12	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
3	13	13	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
4	14	14	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
5	15	15	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
6	16	16	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
7	17	17	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
8	18	18	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
9	19	19	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
10	20	20	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
11	21	21	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 14

* * ESTIMATED DATA STORAGE REQUIREMENTS

	REAL			INTEGER	
INPUT	EXECUTION	AVAILABLE	INPUT	EXECUTION	AVAILABLE
87	330	10000	57	124	1000

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1
SUBROUTINE "STRLNA"

DESIGN VARIABLES SPECIFIED: PE,V

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	= 55.0000
	DENSITY (LBF-SEC2/FT4)	= 1.9384
	VISCOSITY (FT2/SEC)	= 0.122849997E-04
	ATMOSPHERIC PRESSURE (PSIA)	= 14.1000
	WATER VAPORIZATION PRESSURE (PSIA)	= 0.2470
HULL PARAMETERS:	WAKE FRACTION	= 0.2200
	THRUST DEDUCTION FRACTION	= 0.1900
	RELATIVE ROTATIVE EFFICIENCY	= 1.0250
	NUMBER OF PROPELLERS	= 1.0
	DEPTH TO SHAFT CENTERLINE (FT)	= 15.0000
	DIAMETER LIMIT (FT)	= 22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	= 5.0
	MATERIAL TYPE	= STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	= 5400.0
SELECTION VALUES:	PE (HP)	= 18153.0
	V (FT/SEC)	= 40.5120
	N (RPM)	= 631.9868
	QS (FT-LBF)	= 83126272.0
	PD (HP)	= 0.000000000
	J	= 0.1000
	KT	= 0.1879
	KQ	= 0.0160
	ETAC	= 0.1865
	RET75R	= 0.7E+09
	DIA (FT)	= 22.0000
	P/C	= 0.5200
	AE/AO	= 0.3000
	T/C .75R	= 0.0300
CONSTRAINT VALUES:	MAX DIA (FT)	= 22.0000
	MIN AE/AO	= 0.1615
	MIN T/C .75R	= 0.037632

```
                    C C A M I N
              FORTRAN PROGRAM FOR
     CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =  -0.166489E+00

DECISION VARIABLES (X-VECTOR)
  1)    0.300300E+00  0.300000E+02  0.100000E+00  0.500000E+00  0.300000E-01

CONSTRAINT VALUES (G-VECTOR)
  1)   -0.625300E-01 -0.937500E+00 -0.330794E+03 -0.668826E+03  0.150000E+00 -0.750000E+00
  7)   -0.159300E-01 -0.232648E+00 -0.109178E+03  0.363648E+00  0.102878E+03  0.931366E+00
```

```
FINAL OPTIMIZATION INFORMATION

OBJ =  -0.710857E+00

DECISION VARIABLES (X-VECTOR)
  1)    0.82045E+00  0.21995E+02  0.73433E+00  0.99813E+00  0.33004E-01

CONSTRAINT VALUES (G-VECTOR)
  1)   -0.48895E+00 -0.34105E+00 -0.38016E+02 -0.96096E+03 -0.37049E+00 -0.22951E+00
  7)   -0.11E935E-01 -0.22963E+00 -0.16354E-02 -0.31233E-04 -0.35786E+00 -0.33350E+00

THERE ARE    2 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
     9    10

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
     ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR 30 ITERATIONS

NUMBER OF ITERATIONS =   83

OBJECTIVE FUNCTION WAS EVALUATED          548  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       548  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 1 FUNCTION VALUE 0.71086E+00

DESIGN VARIABLES

ID	C. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	3	0.20000E+00	0.92049E+00	0.10000E+01
2	2	7	0.10000E+01	0.31899E+02	0.40000E+02
3	3	21	0.10000E+00	0.13633E+00	0.10000E+01
4	4	7	0.40000E+00	0.99813E+00	0.14000E+01
5	5	9	0.30000E-02	0.33004E-01	0.50000E+00

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.10000E+16	-0.15895E+00	0.0
2	12	-0.10000E+16	-0.31725E+00	0.0
3	13	-0.10000E+16	-0.38014E+02	0.0
4	14	-0.10000E+16	-0.60000E+02	0.0
5	15	-0.10000E+16	-0.37045E+00	0.0
6	16	-0.10000E+16	-0.22933E+00	0.0
7	17	-0.10000E+16	-0.18934E-01	0.0
8	18	-0.10000E+16	-0.22933E+00	0.0
9	19	-0.10000E+16	-0.16231E-02	0.0
10	20	-0.10000E+16	-0.40946E-04	0.0
11	21	-0.10000E+16	-0.35188E+00	0.0
12	22	-0.10000E+16	-0.33344E+00	0.0

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1
SUBROUTINE "STACNA"

DESIGN VARIABLES SPECIFIED: PE,V

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	55.0000
	DENSITY (LBF-SEC2/FT4)	=	1.9384
	VISCOSITY (FT2/SEC)	=	0.12284999 7E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	5.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	9400.0
SELECTION VALUES:	PE (HP)	=	16153.0
	V (FT/SEC)	=	46.5120
	N (RPM)	=	117.3647
	QS (FT-LBF)	=	1375368.0
	PD (HP)	=	24030.30
	J	=	0.7343
	KT	=	0.1713
	KQ	=	0.0282
	ETAC	=	0.7109
	RETA5R	=	0.8E+08
	DIA (FT)	=	21.9991
	P/C	=	0.9981
	AE/AO	=	0.8205
	T/C .75R	=	0.0330
CONSTRAINT VALUES:	MAX DIA (FT)	=	22.0000
	MIN AE/AO	=	0.5269
	MIN T/C .75R	=	0.021998

PROGRAM CALLS TO ANALYZ

ICALC	CALLS
1	1
2	549
5	2



CONTROL PROGRAM
FOR
ENGINEERING SYNTHESIS

TITLE
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CARD IMAGES OF CONTROL DATA

```
CARD                    IMAGE

 1)  $A  TITLE
 2)    WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
 3)  $E    NCALC        NDV          NSV         N2VAR      NXAPRX      IPNPLT      IPDBG
 4)                       5                                                0
 5)  $C   IPRINT       ITMAX       ICPDIR        NSCAL       ITRM      LINOBJ      NALMX
 6)                     1000                         -1         30                       15
 7)  $C1    FDCH       FDCHM          CT        CTMIN        CTL      CTLMIN       THETA
 8)       0.0001      0.0001
 9)  $C2  DELFUN      DABFUN      ALPHAX      ABCOBJ1
10)
11)
12)  $E   NEVTOT        IOBJ      SGNOPT
13)                        1         1.0
14)  $F       VLB         VUB                   X        SCAL
15)           0.2         1.3                0.30         1.0
16)           1.0        >0.0                30.0        10.0
17)         0.001         1.4                 0.1         1.0
18)           0.4         1.5                 0.2         1.0
19)         0.303         0.3           0.0300000       0.010
20)  $G  NCSSGN       IDSGN       APULT
21)                        1           3       1.00
22)                        2           4       1.00
23)                        3           2       1.00
24)                        4           5       1.00
25)                        5           6       1.00
26)  $F    NCONS
27)                       12
28)  $II    ICON        JCON        LCON
29)  $I2      BL       SCALI          BU      SCAL2
30)                        11
31)  -1.0    +16           12         0.0         1.0
32)                        12
33)  -1.0    +16           13         0.0         1.0
34)                        13
35)  -1.0    +16           14         0.0         1.0
36)                        14
37)  -1.0    +16           15         0.0         1.0
38)                        15
39)  -1.0    +16           16         0.0         1.0
40)                        16
41)  -1.0    +16           17         0.0         1.0
42)                        17
43)  -1.0    +16           18         0.0         1.0
44)                        18
45)  -1.0    +16           19         0.0         1.0
46)                        19
47)  -1.0    +16           20         0.0         1.0
48)                        20
49)  -1.0    +16           21         0.0         1.0
50)                        21
51)  -1.0    +16           22         0.0         1.0
52)                        22
53)  -1.0    +16          1.0         0.0         1.0
54)  $I
55)  END
```

TITLE:
MAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CONTROL PARAMETERS:
CALCULATION CONTROL, NCALC =
REDUCED OR FULL DESIGN VARIABLES, NDES =
REDUCED OR FULL CONSTRAINTS, NCON =
REDUCED OR FULL OBJECTIVE, NOBJ =
INPUT VERIFICATION PRINT CODE. IPRIN =
DEBUG OPTION CODE. IDEBG =

CALCULATION CONTROL, NCALC
VALUE MEANING
  1   SINGLE ANALYSIS
  2   GRADIENT ANALYSIS
  3   SENSITIVITY
  4   MULTI-VARIABLE SURFACE FUNCTION SPACE
  5   SET MIN STEP SIZE
  6   APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE =
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	ILINOBJ	MAGMX	MCHG
1	1200	0	-1	30	0	15	0

FDCH	FDCHM	CT	CTMIN
0.1800CE-02	0.1000E-03	0.0	0.0
CTL	CTLMIN	THETA	PHI
0.0	0.0	0.0	0.0
DELFUN	DABFUN	ALPHAX	ABOBJ1
0.0	0.0	0.0	0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

NO.	D. V. LINK	LOWER BOUND	INITIAL VALUE	SCALE
1	C.2000E+00	0.1000E-01	0.3000E+00	0.1000E+01
2	C.1850E+01	0.1000E+01	0.2000E+02	0.1000E+01
3	0.0	0.1000E+01	0.2000E+02	0.1000E+01
4	C.5000E+00	0.1000E+01	0.3000E+01	0.1000E+01
5	C.1850E+02	0.1000E+01	0.3000E+01	0.1000E+01

DESIGN VARIABLES

ID	D. V. FC.	GLOBAL VAR. NO.	MULTIPLYING
1	1	1	0.1000E+01
2	1	2	0.1000E+01
3	1	3	0.1000E+01
4	1	4	0.1000E+01
5	1	5	0.1000E+01

CONSTRAINT INFORMATION

THERE ARE 12 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	1	1	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
2	2	2	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
3	3	3	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
4	4	4	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
5	5	5	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
6	6	6	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
7	7	7	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
8	8	8	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
9	9	9	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
10	10	10	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
11	11	11	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01
12	12	12	0	-0.1000E+01	0.1000E+01	0.	0.1000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 1.

* * ESTIMATED DATA STORAGE REQUIREMENTS

REAL			INTEGER		
INPUT	EXECUTION	AVAILABLE	INPUT	EXECUTION	AVAILABLE
87	370	10000	57	324	1000

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 1
SUBROUTINE "STARNA"

DESIGN VARIABLES SPECIFIED: PE,V

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	59.0000
	DENSITY (LBF-SEC2/FT4)	=	1.9386
	VISCOSITY (FT2/SEC)	=	0.122049997E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1500
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	5.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTION VALUES:	PE (HP)	=	18353.0
	V (FT/SEC)	=	40.5120
	N (RPM)	=	631.9868
	QS (FT-LBF)	=	83126212.0
	PD (HP)	=	0.0000000000
	J	=	0.1000
	KT	=	0.1879
	KQ	=	0.0160
	ETAI	=	0.7865
	RET75R	=	0.7E+08
	DIA (FT)	=	12.0000
	P/D	=	0.9000
	AE/AO	=	0.5000
	T/C .75R	=	0.0300
CONSTRAINT VALUES:	MAX DIA (FT)	=	22.0000
	MIN AE/AO	=	0.1615
	MIN T/C .75R	=	0.198487

C C P M I N

FORTRAN PROGRAM FOR

CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ = -C.166489E+00

DECISION VARIABLES (X-VECTOR)

1)	C.30000E+00	0.30000E+02	0.10000E+00	0.50000E+00	C.30000E-01

CONSTRAINT VALUES (G-VECTOR)

1)	-C.67500E-01	-0.93750E+00	-0.33074E+03	-0.66826E+03	C.15000E+00	-0.75000E+00
7)	-C.15930E-01	-0.23264E+00	-0.10917E+03	0.36364E+00	C.10487E+03	0.56162E+01

```
FINAL OPTIMIZATION INFORMATION

 OBJ =  -0.7C6575E+06

 DECISION VARIABLES (X-VECTOR)
   1)    0.81408E+00  0.21966E+02  0.73936E+00  0.10671E+01  0.641526-01

 CONSTRAINT VALUES (G-VECTOR)
   1)   -0.44210E+00 -0.53755E+03 -0.[illegible]E+04 -0.97361E+03 -0.36408E+00 -0.23916E+00
   7)   -0.5C082E-01 -0.15848E+00  0.17331E-02 -0.19509E-02 -0.35365E+00 -0.16980E+00

 THERE ARE    2 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
      5     10

 THERE ARE    0 VIOLATED CONSTRAINTS

 THERE ARE    0 ACTIVE SIDE CONSTRAINTS

 TERMINATION CRITERION
      ABS((-OBJ(I-1)/OBJ(I-1)) LESS THAN DELFUN FOR 30 ITERATIONS
      ABS(OBJ(I)-OBJ(I-1))     LESS THAN DABFUN FOR 30 ITERATIONS

 NUMBER OF ITERATIONS =   73

 OBJECTIVE FUNCTION WAS EVALUATED          451  TIMES

 CONSTRAINT FUNCTIONS WERE EVALUATED       491  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 1 FUNCTION VALUE 0.7065HE+00

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	3	0.22000E+00	0.81488E+00	0.10000E+01
2	2	4	0.12000E+01	0.21966E+02	0.55000E+02
3	3	23	0.0	0.73936E+00	0.10300E+08
4	4	7	0.54000E+00	0.10071E+01	0.14200E+01
5	5	9	0.32000E-02	0.64152E-01	0.50000E+00

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.11000E+16	-0.46210E+00	0.0
2	12	-0.11000E+16	-0.33790E+00	0.0
3	13	-0.11000E+16	-0.23388E+02	0.0
4	14	-0.11000E+16	-0.47388E+02	0.0
5	15	-0.11000E+16	-0.36448E+02	0.0
6	16	-0.11000E+16	-0.12251E+00	0.0
7	17	-0.11000E+16	-0.50182E-01	0.0
8	18	-0.11000E+16	-0.15844E+00	0.0
9	19	-0.11000E+16	-0.17431E-02	0.0
10	20	-0.11000E+16	-0.13504E-02	0.0
11	21	-0.11000E+16	-0.30342E+00	0.0
12	22	-0.11000E+16	-0.16480E+00	0.0

OPTIMIZATION RESULTS -------	DESIGN CASE NO. 1 SUBROUTINE "STRONK"		
DESIGN VARIABLES SPECIFIED:	PE,V		
ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	55.0000
	DENSITY (LB-SEC2/FT4)	=	1.9384
	VISCOSITY (FT2/SEC)	=	0.1220469972E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2475
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH AT SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	22.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	5.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTION VALUES:	PE (HP)	=	18153.0
	V (FT/SEC)	=	46.5120
	N (RPM)	=	114.7419
	QS (FT-LBF)	=	1584003.0
	PD (HP)	=	24694.79
	J	=	0.7394
	KT	=	0.1736
	KQ	=	0.0249
	ETAC	=	0.7066
	REY75R	=	0.5E+08
	DIA (FT)	=	21.9659
	P/D	=	1.0071
	AE/AC	=	0.8169
	T/C .75R	=	0.0642
CONSTRAINT VALUES:	MAX DIA (FT)	=	22.0000
	MIN AE/AO	=	0.5267
	MIN T/C .75R	=	0.053259

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	45
3	2

```
      SUBROUTINE ANALIZ(ICALC)                                                  APPOC010
      INTEGER*4 ICALC                                                           APPOC020
      REAL*4 ETAO,WEIGHT,AEDVAO,DIA,N,PE,FDIVD,GS,TC75R,V,                      APPOC030
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,             APPOC040
     2       FCWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                    APPOC050
     3       VK,TC,WT,Z,WATRC,WATNU,TEMP,NOSCRW,HCL,PATM,                       APPOC060
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                       APPOC070
     5       C75R,R75R,KT,KC,PD,VAK                                             APPOC080
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAO,DIA,N,PE,FDIVD,GS,TC75R,V,RJCNL,        APPOC090
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,            APPOC100
     2AEACCV,TCSTRS,RJ                                                          APPOC110
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NOSCRW,HCL,PATM,PWATVA,         APPOC120
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                      APPOC130
C                                                                               APPOC140
CCC   THIS SUBROUTINE, COUPLED WITH COPES/CONMIN, CONSTITUTES ANALYSIS          APPOC150
CCC   METHOD FOR "DESIGN CASE 2" PROPELLER SELECTION PROBLEMS                   APPOC160
CCCCC                                                                           APPOC170
CCC   INPUT-INITIALIZATION PHASE                                                APPOC180
C                                                                               APPOC190
      PII=3.14159264                                                            APPOC200
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                              APPOC210
CC                                                                              APPOC220
CCC         SET "DESIGN CASE 2" PARAMETERS                                      APPOC230
CCCC                                                                            APPOC240
CCC         ENVIRONMENTAL                                                       APPOC250
CC                                                                              APPOC260
            TEMP=64.4                                                           APPOC270
            WATRO=1.9852                                                        APPOC280
            WATNU=.000011900                                                    APPOC290
            PATM=14.697                                                         APPOC300
            PWATVA=.29543291                                                    APPOC310
CC                                                                              APPOC320
CCC         PROPELLER PARAMETERS                                                APPOC330
CC                                                                              APPOC340
            Z=6.0                                                               APPOC350
            PROMAT=5.0                                                          APPOC360
CC                                                                              APPOC370
CCC         HULL PARAMETERS                                                     APPOC380
CC                                                                              APPOC390
            WT=0.22                                                             APPOC400
            TC=0.19                                                             APPOC410
            ETARR=1.025                                                         APPOC420
            NOSCRW=1.0                                                          APPOC430
            HCL=21.9827                                                         APPOC440
            DIALIM=30.0                                                         APPOC450
CC                                                                              APPOC460
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 2"                 APPOC470
CC                                                                              APPOC480
```

```
      QS=121C129.835                                                    APP0C490
      N=110.C                                                           APP0C500
      VK=20.(641C256                                                    APP0C510
      V=1.68E*VK                                                        APP0C520
CC                                                                      APP0C530
CC          END OF INPUT-INITIALIZATION PHASE                           APP0C540
CC                                                                      APP0C550
      GO TO 3                                                           APP0C560
C                                                                       APP0C570
C     EXECUTION PHASE                                                   APP0C580
C                                                                       APP0C590
    1 CONTINUE                                                          APP0C600
      IF(.NOT.(ICALC.EC.2))GO TO 2                                      APP0C610
      TC75R=((0.C185-0.C0125*Z)*Z)/(2.073*AEDVAO)                       APP0C620
      CALL RICAL(DIA)                                                   APP0C630
      CALL CF75RA(C75K)                                                 APP0C640
      CALL REY75R(C75R,R75R)                                            APP0C650
      CALL CCEFSA(RJ,R75R,KT,KQ)                                        APP0C660
      CALL OPWEFF(RJ,KT,KQ,ETAO)                                        APP0C670
      CALL CALCPE(KT,PE)                                                APP0C680
      CALL JCNA(RJ,RJCNL,RJCNU)                                         APP0C690
      CALL REYCNA(R75R,R75RCL,R75RCU)                                   APP0C700
      CALL EXTCCN(Z,AEDVAO,TC75R,AEAOCL,AEAOCU,TC75CL,TC75CU)           APP0C710
      CALL BLPOW2(KQ,PCHBAL)                                            APP0C720
      CALL DICNUA(DIACNU)                                               APP0C730
      CALL CAVCNA(KT,AEACCV)                                            APP0C740
      CALL STRCNA(KQ,C75R,TCSTRS)                                       APP0C750
CC                                                                      APP0C760
CC          END OF EXECUTION PHASE                                      APP0C770
CC                                                                      APP0C780
      GO TO 3                                                           APP0C790
    2 CONTINUE                                                          APP0C800
C                                                                       APP0C810
C     OUTPUT-RESULT PHASE                                               APP0C820
C                                                                       APP0C830
      VK=V/1.688                                                        APP0C840
      VAK=(1.0-WT)*VK                                                   APP0C850
      PC=(2.C*PII*QS*N)/33000.0                                         APP0C860
      WRITE(6,9000)                                                     APP0C870
      WRITE(6,9001)                                                     APP0C880
      WRITE(6,9002)TEMP,WATRO,WATNU,PATM,PWATVA                         APP0C890
      WRITE(6,9003)WT,TD,ETARR,NOSCRW,HCL,DIALIM                        APP0C900
      WRITE(6,9004)Z                                                    APP0C910
      IF(.NOT.(PROMAT.EC.1.0))GO TO 81                                  APP0C920
          WRITE(6,9005)SC                                               APP0C930
      GO TO 66                                                          APP0C940
   81 CONTINUE                                                          APP0C950
      IF(.NOT.(PROMAT.EC.2.0))GO TO 82                                  APP0C960
```

```
            WRITE(6,9006)SC                                                     APPCCC570
          GO TO 86                                                              APPCCC580
   82     CONTINUE                                                              APPCCC590
          IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                                      APPC1000
            WRITE(6,9007)SC                                                     APPC1010
          GO TO 86                                                              APPC1020
   83     CONTINUE                                                              APPC1030
          IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                      APPC1040
            WRITE(6,9008)SC                                                     APPC1050
          GO TO 86                                                              APPC1060
   84     CONTINUE                                                              APPC1070
          IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                      APPC1080
            WRITE(6,9009)SC                                                     APPC1090
          GO TO 86                                                              APPC1100
   85     CONTINUE                                                              APPC1110
            WRITE(6,9010)                                                       APPC1120
   86     CONTINUE                                                              APPC1130
          WRITE(6,9011)PE,V,VK,VAK,N,QS,PD,RJ,KT,KQ,ETAO,K75R,DIA,              APPC1140
     1                 PDIVD,AEDVAD,TC75R                                       APPC1150
          WRITE(6,9012)DIALIM,AEAOMN,TC75MN                                     APPC1160
    3 CONTINUE                                                                  APPC1170
      RETURN                                                                    APPC1180
C                                                                               APPC1190
C     MISCELLANEOUS FORMAT STATEMENTS                                           APPC1200
C                                                                               APPC1210
 9000 FORMAT('1','OPTIMIZATION RESULTS ------- DESIGN CASE NO. 2',/,            APPC1220
     1       1X,'                                SUBROUTINE "STRCNA"',///)      APPC1230
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  QS,N,V,TC75R',//)                 APPC1240
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',           APPC1250
     1       F10.4,/,                                                           APPC1260
     2       1X,29X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,                   APPC1270
     3       1X,29X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                      APPC1280
     4       1X,29X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,               APPC1290
     5       1X,29X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,//)             APPC1300
 9003 FORMAT(1X,'FULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,         APPC1310
     1       1X,29X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,                 APPC1320
     2       1X,29X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,              APPC1330
     3       1X,29X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                     APPC1340
     4       1X,29X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,            APPC1350
     5       1X,29X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,//)                     APPC1360
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',          APPC1370
     1       F10.1)                                                             APPC1380
 9005 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                       APPC1390
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APPC1400
 9006 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                      APPC1410
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APPC1420
 9007 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  BRONZE',/,                          APPC1430
     1       1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APPC1440
```

```
9008 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                    APP01450
     1      1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP01460
9009 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                 APP01470
     1      1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP01480
9010 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',/)                  APP01490
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,              APP01500
     2      1X,25X,'V   (FT/SEC)',23X,'=',F10.4,/,                            APP01510
     2      1X,25X,'V   (KNOTS )',23X,'=',F10.4,/,                            APP01520
     2      1X,25X,'VA  (KNOTS )',23X,'=',F10.4,/,                            APP01530
     3      1X,25X,'N   (RPM)  ',23X,'=',F10.4,/,                             APP01540
     4      1X,25X,'QS  (FT-LBF)',23X,'=',F12.1,/,                            APP01550
     5      1X,25X,'PD  (HP)   ',23X,'=',F10.2,//,                            APP01560
     6      1X,25X,'J          ',23X,'=',F10.4,/,                             APP01570
     7      1X,25X,'KT         ',23X,'=',F10.4,/,                             APP01580
     8      1X,25X,'KQ         ',23X,'=',F10.4,/,                             APP01590
     9      1X,25X,'ETAC       ',23X,'=',F10.4,/,                             APP01600
     A      1X,25X,'REY75R     ',23X,'=',E10.1,/,                             APP01610
     B      1X,25X,'DIA (FT)   ',23X,'=',F10.4,/,                             APP01620
     C      1X,25X,'P/D        ',23X,'=',F10.4,/,                             APP01630
     D      1X,25X,'AE/AC      ',23X,'=',F10.4,/,                             APP01640
     E      1X,25X,'T/C .75R   ',23X,'=',F10.4,///)                           APP01650
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,        APP01660
     1      1X,25X,'MIN AE/AO',25X,'=',F10.4,/,                               APP01670
     2      1X,25X,'MIN T/C .75R',22X,'=',F10.6)                              APP01680
       END                                                                     APP01690
```

```
      SUBROUTINE ANALIZ(ICALC)                                          APP01720
      INTEGER*4 ICALC                                                   APP01730
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,              APP01740
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEACCU,TC75CL,TC75CU,     APP01750
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                            APP01760
     3       VK,TD,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,               APP01770
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP01780
     5       C75R,R75R,KT,KQ,PD,VAK                                     APP01790
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP01800
     1RJCNU,R75RCL,R75RCU,AEACCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,    APP01810
     2AEACCV,TCSTRS,RJ                                                  APP01820
      COMMON /PARAM/VK,TD,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA, APP01830
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP01840
C                                                                       APP01850
C     THIS SUBROUTINE, COUPLED WITH COPES/COMMIN, CONSTITUTES ANALYSIS  APP01860
C     METHOD FOR "DESIGN CASE 2" PROPELLER SELECTION PROBLEMS           APP01870
C                                                                       APP01880
C     INPUT-INITIALIZATION PHASE                                        APP01890
C                                                                       APP01900
      PII=3.14159264                                                    APP01910
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                      APP01920
CC                                                                      APP01930
CC          SET "DESIGN CASE 2" PARAMETERS                              APP01940
CC                                                                      APP01950
CC          ENVIRONMENTAL                                               APP01960
CC                                                                      APP01970
            TEMP=64.4                                                   APP01980
            WATRO=1.9852                                                APP01990
            WATNU=.000011500                                            APP02000
            PATM=14.697                                                 APP02010
            PWATVA=.29543921                                            APP02020
CC                                                                      APP02030
CC          PROPELLER PARAMETERS                                        APP02040
CC                                                                      APP02050
            Z=6.0                                                       APP02060
            PROMAT=5.0                                                  APP02070
CC                                                                      APP02080
CC          HULL PARAMETERS                                             APP02090
CC                                                                      APP02100
            WT=0.22                                                     APP02110
            TD=0.15                                                     APP02120
            ETARR=1.025                                                 APP02130
            NCSCRW=1.0                                                  APP02140
            HCL=21.9827                                                 APP02150
            DIALIM=30.0                                                 APP02160
CC                                                                      APP02170
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 2"         APP02180
CC                                                                      APP02190
```

```
      QS=121(129.835                                                    APP02200
      N=110.C                                                           APP02210
      VK=20.(641025E                                                    APP02220
      V=1.68E*VK                                                        APP02230
CC                                                                      APP02240
CC          END OF INPUT-INITIALIZATION PHASE                           APP02250
CC                                                                      APP02260
      GO TO 3                                                           APP02270
C                                                                       APP02280
CC    EXECUTION PHASE                                                   APP02290
C                                                                       APP02300
    1 CONTINUE                                                          APP02310
      IF(.NOT.(ICALC.EQ.2))GO TO 2                                      APP02320
      TC75R=((0.0185-0.C0125*Z)*Z)/(2.073*AECVAO)                       APP02330
      CALL RCCAL(DIA)                                                   APP02340
      CALL C75RA(C75R)                                                  APP02350
      CALL REY75R(C75R,R75R)                                            APP02360
      CALL CCEFSA(RJ,R75R,KT,KQ)                                        APP02370
      CALL OPWEFF(RJ,KT,KQ,ETAO)                                        APP02380
      CALL CALCPE(KT,PE)                                                APP02390
      CALL JCNA(RJ,RJCNL,RJCNU)                                         APP02400
      CALL REYCNA(R75R,R75RCL,R75RCU)                                   APP02410
      CALL E)TCCN(Z,AECVAO,TC75R,AEACCL,AEAOCU,TC75CL,TC75CU)           APP02420
      CALL BLPOW2(KC,POWBAL)                                            APP02430
      CALL DICNUA(DIACNU)                                               APP02440
      CALL CAVCNA(KT,AEAOCV)                                            APP02450
      CALL STRCNK(KC,KT,C75R,TCSTRS)                                    APP02460
CC                                                                      APP02470
CC          END OF EXECUTION PHASE                                      APP02480
CC                                                                      APP02490
      GO TO 3                                                           APP02500
    2 CONTINUE                                                          APP02510
C                                                                       APP02520
CC    OUTPUT-RESULT PHASE                                               APP02530
C                                                                       APP02540
      VK=V/1.688                                                        APP02550
      VAK=(1.0-WT)*VK                                                   APP02560
      PC=(2.C*PI*QS*N)/33000.0                                          APP02570
      WRITE(6,9000)                                                     APP02580
      WRITE(6,9001)                                                     APP02590
      WRITE(6,9002)TEMP,WATRO,WATNU,PATM,PWATVA                         APP02600
      WRITE(6,9003)WT,TD,ETARR,NOSCRW,HCL,DIALIM                        APP02610
      WRITE(6,9004)Z                                                    APP02620
      IF(.NOT.(PROMAT.EQ.1.0))GO TO 81                                  APP02630
         WRITE(6,9005)SC                                                APP02640
      GO TO 86                                                          APP02650
   81 CONTINUE                                                          APP02660
      IF(.NOT.(PROMAT.EQ.2.0))GO TO 82                                  APP02670
```

```
                WRITE(6,9006)SC                                                 APPO2680
            GO TO 86                                                            APPO2690
   82       CONTINUE                                                            APPO2700
            IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                                    APPO2710
                WRITE(6,9007)SC                                                 APPO2720
            GO TO 86                                                            APPO2730
   83       CONTINUE                                                            APPO2740
            IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                    APPO2750
                WRITE(6,9008)SC                                                 APPO2760
            GO TO 86                                                            APPO2770
   84       CONTINUE                                                            APPO2780
            IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                    APPO2790
                WRITE(6,9009)SC                                                 APPO2800
            GO TO 86                                                            APPO2810
   85       CONTINUE                                                            APPO2820
                WRITE(6,9010)                                                   APPO2830
   86       CONTINUE                                                            APPO2840
            WRITE(6,9011)PE,V,VK,VAK,N,QS,PD,RJ,KT,KQ,ETAO,R75R,DIA,            APPO2850
     1                   PCIVC,AECVAO,TC75R                                     APPO2860
            WRITE(6,9012)DIALIM,AEAOMN,TC75MN                                   APPO2870
     3  CONTINUE                                                               APPO2880
         RETURN                                                                 APPO2890
C                                                                               APPO2900
CC       MISCELLANEOUS FORMAT STATEMENTS                                        APPO2910
C                                                                               APPO2920
 9000 FORMAT('1','OPTIMIZATION RESULTS ------- DESIGN CASE NO. 2',/,            APPO2930
     1       1X,'                              SUBROUTINE "STRCNK"',///)        APPO2940
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  QS,N,V,TC75R',/)                  APPO2950
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',           APPO2960
     1       F10.4,/,                                                         APPO2970
     2       1X,25X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,                 APPO2980
     3       1X,25X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                    APPO2990
     4       1X,25X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,             APPO3000
     5       1X,25X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,///)          APPO3010
 9003 FORMAT(1X,'FULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,        APPO3020
     1       1X,25X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,               APPO3030
     2       1X,25X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,            APPO3040
     3       1X,25X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                   APPO3050
     4       1X,25X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,          APPO3060
     5       1X,25X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,///)                  APPO3070
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',        APPO3080
     1       F10.1)                                                           APPO3090
 9005 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                     APPO3100
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                 APPO3110
 9006 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                    APPO3120
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                 APPO3130
 9007 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  BRONZE',/,                        APPO3140
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                 APPO3150
```

```
9008 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                    APP03160
     1      1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP03170
9009 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                 APP03180
     1      1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                   APP03190
901C FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NCT CONSIDERED',/)                  APP03200
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,              APP03210
     2      1X,25X,'V  (FT/SEC)',23X,'=',F10.4,/,                             APP03220
     2      1X,25X,'V  (KNOTS )',23X,'=',F10.4,/,                             APP03230
     2      1X,25X,'VA (KNOTS )',23X,'=',F10.4,/,                             APP03240
     3      1X,25X,'N  (RPM)   ',23X,'=',F10.4,/,                             APP03250
     4      1X,25X,'CS (FT-LBF)',23X,'=',F12.1,/,                             APP03260
     5      1X,25X,'PD  (HP)   ',23X,'=',F10.2,//,                            APP03270
     6      1X,25X,'J          ',23X,'=',F10.4,/,                             APP03280
     7      1X,25X,'KT         ',23X,'=',F10.4,/,                             APP03290
     8      1X,25X,'KQ         ',23X,'=',F10.4,/,                             APP03300
     9      1X,25X,'ETAO       ',23X,'=',F10.4,/,                             APP03310
     A      1X,25X,'REY75R     ',23X,'=',E10.1,/,                             APP03320
     B      1X,25X,'DIA (FT)   ',23X,'=',F10.4,/,                             APP03330
     C      1X,25X,'P/D        ',23X,'=',F10.4,/,                             APP03340
     D      1X,25X,'AE/AO      ',23X,'=',F10.4,/,                             APP03350
     E      1X,25X,'T/C .75R   ',23X,'=',F10.4,///)                           APP03360
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,        APP03370
     1      1X,25X,'MIN AE/AO',25X,'=',F10.4,/,                               APP03380
     2      1X,25X,'MIN T/C .75R',22X,'=',F10.6)                              APP03390
      END                                                                      APP03400
```

```
      SUBROUTINE ANALIZ(ICALC)                                          APP03430
      INTEGER*4 ICALC                                                   APP03440
      REAL*4 ETAO,WEIGHT,AEOVAO,DIA,N,PE,FDIVD,QS,TC75R,V,              APP03450
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP03460
     2       POWBAL,DIACNU,AEAOCV,TCSTFS,RJ,                            APP03470
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,               APP03480
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP03490
     5       C75R,R75R,KT,KC,PD,VAK                                     APP03500
      COMMON /GLOBCM/ETAO,WEIGHT,AEOVAO,DIA,N,PE,FDIVD,QS,TC75R,V,RJCNL,APP03510
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,    APP03520
     2AEAOCV,TCSTFS,RJ                                                  APP03530
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA, APP03540
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP03550
C                                                                       APP03560
C     THIS SUBROUTINE, COUPLED WITH COPES/COMMIN, CONSTITUTES ANALYSIS  APP03570
C     METHOD FOR "DESIGN CASE 2" PROPELLER SELECTION PROBLEMS           APP03580
C                                                                       APP03590
C     INPUT-INITIALIZATION PHASE                                        APP03600
C                                                                       APP03610
      PI=3.14159264                                                     APP03620
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                      APP03630
CC                                                                      APP03640
CC          SET "DESIGN CASE 2" PARAMETERS                              APP03650
CC                                                                      APP03660
CC          ENVIRONMENTAL                                               APP03670
CC                                                                      APP03680
            TEMP=64.4                                                   APP03690
            WATRO=1.9852                                                APP03700
            WATNU=.000011900                                            APP03710
            PATM=14.697                                                 APP03720
            PWATVA=.29543291                                            APP03730
CC                                                                      APP03740
CC          PROPELLER PARAMETERS                                        APP03750
CC                                                                      APP03760
            Z=6.0                                                       APP03770
            PROMAT=5.0                                                  APP03780
CC                                                                      APP03790
CC          HULL PARAMETERS                                             APP03800
CC                                                                      APP03810
            WT=0.22                                                     APP03820
            TC=0.15                                                     APP03830
            ETARR=1.025                                                 APP03840
            NCSCRW=1.0                                                  APP03850
            HCL=21.9827                                                 APP03860
            DIALIM=30.0                                                 APP03870
CC                                                                      APP03880
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 2"         APP03890
CC                                                                      APP03900
```

```
                QS=121(125.835                                                  APP03910
                N=110.C                                                         APP03920
CC                                                                              APP03930
CC              END OF INPUT-INITIALIZATION PHASE                               APP03940
CC                                                                              APP03950
          GO TO 3                                                               APP03960
C                                                                               APP03970
C         EXECUTION PHASE                                                       APP03980
C                                                                               APP03990
      1 CONTINUE                                                                APP04000
          IF(.NOT.(ICALC.EQ.2))GO TO 2                                          APP04010
                CALL RECAL(DIA)                                                 APP04020
                CALL CF75RA(C75R)                                               APP04030
                CALL REY75R(C75R,R75R)                                          APP04040
                CALL CCEFSA(RJ,R75R,KT,KQ)                                      APP04050
                CALL OFWEFF(RJ,KT,KQ,ETAO)                                      APP04060
                CALL CALCPE(KT,PE)                                              APP04070
                CALL JCNA(RJ,RJCNL,RJCNU)                                       APP04080
                CALL REYCNA(R75R,R75RCL,R75RCU)                                 APP04090
                CALL EXTCCN(Z,AEDVAO,TC75R,AEACCL,AEAOCU,TC75CL,TC75CU)         APP04100
                CALL BLPOW2(KC,POWBAL)                                          APP04110
                CALL DICNUA(DIACNL)                                             APP04120
                CALL CAVCNA(KT,AEAOCV)                                          APP04130
                CALL STRCNA(KC,C75R,TCSTRS)                                     APP04140
CC                                                                              APP04150
CC              END OF EXECUTION PHASE                                          APP04160
CC                                                                              APP04170
          GO TO 3                                                               APP04180
      2 CONTINUE                                                                APP04190
C                                                                               APP04200
C         OUTPUT-RESULT PHASE                                                   APP04210
C                                                                               APP04220
                VK=V/1.688                                                      APP04230
                VAK=(1.0-WT)*VK                                                 APP04240
                PC=(2.C*PII*QS*N)/33000.0                                       APP04250
                WRITE(6,9000)                                                   APP04260
                WRITE(6,9001)                                                   APP04270
                WRITE(6,9002)TEMP,WATRO,WATNU,PATM,PWATVA                       APP04280
                WRITE(6,9003)WT,TD,ETARR,NOSCRW,HCL,DIALIM                      APP04290
                WRITE(6,9004)Z                                                  APP04300
                IF(.NOT.(PROMAT.EQ.1.0))GO TO 81                                APP04310
                    WRITE(6,9005)SC                                             APP04320
                GO TO 86                                                        APP04330
     81         CONTINUE                                                        APP04340
                IF(.NOT.(PROMAT.EQ.2.0))GO TO 82                                APP04350
                    WRITE(6,9006)SC                                             APP04360
                GO TO 86                                                        APP04370
     82         CONTINUE                                                        APP04380
```

```
      IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                                  APP04390
         WRITE(6,9007)SC                                                APP04400
      GO TO 86                                                          APP04410
   83 CONTINUE                                                          APP04420
      IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                  APP04430
         WRITE(6,9008)SC                                                APP04440
      GO TO 86                                                          APP04450
   84 CONTINUE                                                          APP04460
      IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                  APP04470
         WRITE(6,9009)SC                                                APP04480
      GO TO 86                                                          APP04490
   85 CONTINUE                                                          APP04500
         WRITE(6,9010)                                                  APP04510
   86 CONTINUE                                                          APP04520
      WRITE(6,9011)PE,V,VK,VAK,N,DS,PD,RJ,KT,KQ,ETAO,R75R,DIA,          APP04530
     1             PDIVD,AEDVAD,TC75R                                   APP04540
      WRITE(6,9012)DIALIM,AEAOMA,TC75MN                                 APP04550
    3 CONTINUE                                                          APP04560
      RETURN                                                            APP04570
C                                                                       APP04580
C     MISCELLANEOUS FORMAT STATEMENTS                                   APP04590
C                                                                       APP04600
 9000 FORMAT('1','OPTIMIZATION RESULTS -----   DESIGN CASE NO. 2',/,    APP04610
     1       1X,'                              SUBROUTINE "STRCNA"',///) APP04620
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  DS,N',//)                 APP04630
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',    APP04640
     1       F10.4,/,                                                   APP04650
     1       1X,25X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,           APP04660
     2       1X,25X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,              APP04670
     3       1X,25X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,       APP04680
     4       1X,25X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,//)     APP04690
 9003 FORMAT(1X,'HULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,  APP04700
     1       1X,25X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,         APP04710
     2       1X,25X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,      APP04720
     3       1X,25X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,             APP04730
     4       1X,25X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,    APP04740
     5       1X,25X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,///)            APP04750
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',   APP04760
     1       F10.1)                                                     APP04770
 9005 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST IRON',/,               APP04780
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)          APP04790
 9006 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,              APP04800
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)          APP04810
 9007 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  BRONZE',/,                  APP04820
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)          APP04830
 9008 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,            APP04840
     1       1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)          APP04850
 9009 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,         APP04860
```

```
     1          1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1//)                  APP04870
9010 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',//)                    APP04880
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,                 APP04890
     1          1X,25X,'V  (FT/SEC)',23X,'=',F10.4,/,                            APP04900
     2          1X,25X,'V  (KNOTS )',23X,'=',F10.4,/,                            APP04910
     3          1X,25X,'VA (KNOTS )',23X,'=',F10.4,/,                            APP04920
     4          1X,25X,'N  (RPM)   ',23X,'=',F10.4,/,                            APP04930
     5          1X,25X,'QS (FT-LBF)',23X,'=',F12.1,/,                            APP04940
     6          1X,25X,'PD  (HP)   ',23X,'=',F10.2,//,                           APP04950
     7          1X,25X,'J          ',23X,'=',F10.4,/,                            APP04960
     8          1X,25X,'KT         ',23X,'=',F10.4,/,                            APP04970
     9          1X,25X,'KQ         ',23X,'=',F10.4,/,                            APP04980
     A          1X,25X,'ETAC       ',23X,'=',F10.4,/,                            APP04990
     B          1X,25X,'REY 75R    ',23X,'=',E10.1,/,                            APP05000
     C          1X,25X,'DIA (FT)   ',23X,'=',F10.4,/,                            APP05010
     D          1X,25X,'P/D        ',23X,'=',F10.4,/,                            APP05020
     E          1X,25X,'AE/AO      ',23X,'=',F10.4,/,                            APP05030
     F          1X,25X,'T/C .75R   ',23X,'=',F10.4,//)                           APP05040
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,          APP05050
     1          1X,25X,'MIN AE/AO',25X,'=',F10.4,/,                              APP05060
     2          1X,25X,'MIN T/C .75R',22X,'=',F10.6)                             APP05070
      END                                                                         APP05080
```

```
      SUBROUTINE ANALIZ(ICALC)                                          APP05110
      INTEGER*4 ICALC                                                   APP05120
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,              APP05130
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,     APP05140
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                            APP05150
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,               APP05160
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,               APP05170
     5       C75R,R75R,KT,KC,PD,VAK                                     APP05180
      COMMON /GLOECM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,PDIVD,QS,TC75R,V,RJCNL,APP05190
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,    APP05200
     2AEACCV,TCSTRS,RJ                                                  APP05210
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNL,TEMP,NCSCRW,HCL,PATM,PWATVA,  APP05220
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                              APP05230
C                                                                       APP05240
C     THIS SUBROUTINE, COUPLED WITH COPES/CONMIN, CONSTITUTES ANALYSIS  APP05250
C     METHOD FOR "DESIGN CASE 2" PROPELLER SELECTION PROBLEMS           APP05260
C                                                                       APP05270
C     INPUT-INITIALIZATION PHASE                                        APP05280
C                                                                       APP05290
      PI=3.14159264                                                     APP05300
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                      APP05310
CC                                                                      APP05320
CC          SET "DESIGN CASE 2" PARAMETERS                              APP05330
CC                                                                      APP05340
CC          ENVIRONMENTAL                                               APP05350
CC                                                                      APP05360
            TEMP=64.4                                                   APP05370
            WATRO=1.9852                                                APP05380
            WATNU=.000011900                                            APP05390
            PATM=14.697                                                 APP05400
            PWATVA=.29543291                                            APP05410
CC                                                                      APP05420
CC          PROPELLER PARAMETERS                                        APP05430
CC                                                                      APP05440
            Z=6.0                                                       APP05450
            PROMAT=5.0                                                  APP05460
CC                                                                      APP05470
CC          HULL PARAMETERS                                             APP05480
CC                                                                      APP05490
            WT=0.22                                                     APP05500
            TC=0.15                                                     APP05510
            ETARR=1.025                                                 APP05520
            NCSCRW=1.0                                                  APP05530
            HCL=21.9827                                                 APP05540
            DIALIM=30.0                                                 APP05550
CC                                                                      APP05560
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 2"         APP05570
CC                                                                      APP05580
```

```
      QS=121(129.835                                                    APP05590
      N=110.C                                                           APP05600
CC                                                                      APP05610
CC          END OF INPUT-INITIALIZATION PHASE                           APP05620
CC                                                                      APP05630
      GO TO 3                                                           APP05640
C                                                                       APP05650
C     EXECUTION PHASE                                                   APP05660
C                                                                       APP05670
    1 CONTINUE                                                          APP05680
      IF(.NOT.(ICALC.EQ.2))GO TO 2                                      APP05690
          CALL RECAL(DIA)                                               APP05700
          CALL C175RA(C75R)                                             APP05710
          CALL REY75R(C75R,R75R)                                        APP05720
          CALL CCEFSA(RJ,R75R,KT,KQ)                                    APP05730
          CALL OFWEFF(RJ,KT,KQ,ETAO)                                    APP05740
          CALL CALCPE(KT,PE)                                            APP05750
          CALL JCNA(RJ,RJCNL,RJCNU)                                     APP05760
          CALL REYCNA(R75R,R75RCL,R75RCU)                               APP05770
          CALL EXTCCN(Z,AEDVAO,TC75R,AEACCL,AEAOCU,TC75CL,TC75CU)       APP05780
          CALL BLPOW2(KC,POWBAL)                                        APP05790
          CALL DICNUA(DIACNU)                                           APP05800
          CALL CAVCNA(KT,AEAOCV)                                        APP05810
          CALL STRCNK(KC,KT,C75R,TCSTRS)                                APP05820
CC                                                                      APP05830
CC          END OF EXECUTION PHASE                                      APP05840
CC                                                                      APP05850
      GO TO 3                                                           APP05860
    2 CONTINUE                                                          APP05870
C                                                                       APP05880
C     OUTPUT-RESULT PHASE                                               APP05890
C                                                                       APP05900
          VK=V/1.688                                                    APP05910
          VAK=(1.0-WT)*VK                                               APP05920
          PC=(2.C*PII*QS*N)/33000.0                                     APP05930
          WRITE(6,9000)                                                 APP05940
          WRITE(6,9001)                                                 APP05950
          WRITE(6,9002)TEMP,WATRO,WATNU,PATM,PWATVA                     APP05960
          WRITE(6,9003)WT,TD,ETARR,NOSCRW,HCL,DIALIM                    APP05970
          WRITE(6,9004)Z                                                APP05980
          IF(.NOT.(PROMAT.EC.1.0))GO TO 81                              APP05990
              WRITE(6,9005)SC                                           APP06000
          GO TO 86                                                      APP06010
   81     CONTINUE                                                      APP06020
          IF(.NOT.(PROMAT.EC.2.0))GO TO 82                              APP06030
              WRITE(6,9006)SC                                           APP06040
          GO TO 86                                                      APP06050
   82     CONTINUE                                                      APP06060
```

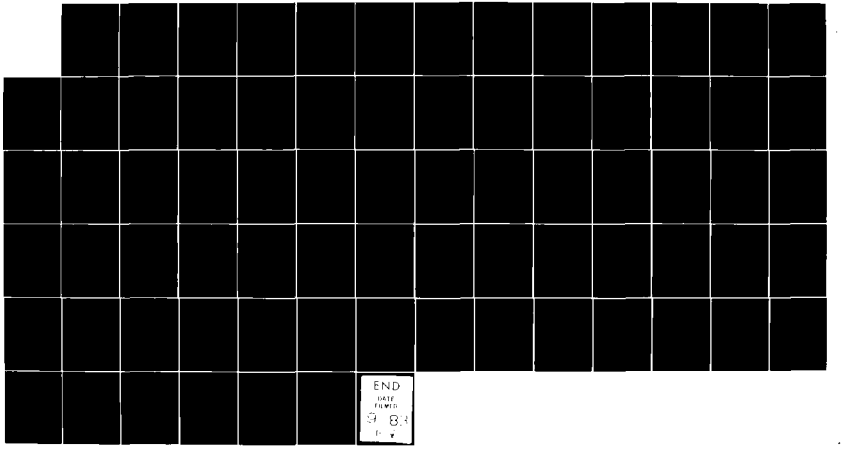
```
            IF(.NOT.(PROMAT.EQ.3.0))GO TO 83                                    APP06070
                WRITE(6,9007)SC                                                 APP06080
            GO TO 86                                                            APP06090
   83       CONTINUE                                                            APP06100
            IF(.NOT.(PROMAT.EQ.4.0))GO TO 84                                    APP06110
                WRITE(6,9008)SC                                                 APP06120
            GO TO 86                                                            APP06130
   84       CONTINUE                                                            APP06140
            IF(.NOT.(PROMAT.EQ.5.0))GO TO 85                                    APP06150
                WRITE(6,9009)SC                                                 APP06160
            GO TO 86                                                            APP06170
   85       CONTINUE                                                            APP06180
                WRITE(6,9010)                                                   APP06190
   86       CONTINUE                                                            APP06200
            WRITE(6,9011)PE,V,VK,VAK,N,DS,D,RJ,KT,KQ,ETAO,R75R,DIA,             APP06210
     1                   PDIVD,AEDVAO,TC75D                                     APP06220
            WRITE(6,9012)DIALIM,AEAOMN,TC75MN                                   APP06230
    3  CONTINUE                                                                 APP06240
       RETURN                                                                   APP06250
C                                                                               APP06260
C      MISCELLANEOUS FORMAT STATEMENTS                                          APP06270
C                                                                               APP06280
 9000  FORMAT('1','OPTIMIZATION RESULTS -----   DESIGN CASE NO. 2',/,          APP06290
     1        1X,'                              SUBROUTINE "STRCNK"',///)       APP06300
 9001  FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  DS,N',//)                        APP06310
 9002  FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',          APP06320
     1        F10.4,/,                                                          APP06330
     1        1X,25X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,                  APP06340
     2        1X,25X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                     APP06350
     3        1X,25X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,              APP06360
     4        1X,25X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,///)           APP06370
 9003  FORMAT(1X,'HULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,         APP06380
     1        1X,25X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,                APP06390
     2        1X,25X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,             APP06400
     3        1X,25X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                    APP06410
     4        1X,25X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,           APP06420
     5        1X,25X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,///)                   APP06430
 9004  FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',         APP06440
     1        F10.1)                                                            APP06450
 9005  FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                      APP06460
     1        1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP06470
 9006  FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                     APP06480
     1        1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP06490
 9007  FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  BRONZE',/,                         APP06500
     1        1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP06510
 9008  FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                   APP06520
     1        1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP06530
 9009  FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                APP06540
```

```
     1        1X,29X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,//)                  APP06550
9010 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',//)                   APP06560
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,                APP06570
     1       1X,29X,'V  (FT/SEC)',23X,'=',F10.4,/,                              APP06580
     2       1X,29X,'V  (KNOTS )',23X,'=',F10.4,/,                              APP06590
     3       1X,29X,'VA (KNOTS )',23X,'=',F10.4,/,                              APP06600
     4       1X,29X,'N  (RPM)   ',23X,'=',F10.4,/,                              APP06610
     5       1X,29X,'CS (FT-LBF)',23X,'=',F12.1,/,                              APP06620
     6       1X,29X,'PD  (HP)   ',23X,'=',F10.2,//,                             APP06630
     7       1X,29X,'J          ',23X,'=',F10.4,/,                              APP06640
     8       1X,29X,'KT         ',23X,'=',F10.4,/,                              APP06650
     9       1X,29X,'KQ         ',23X,'=',F10.4,/,                              APP06660
     A       1X,29X,'ETAC       ',23X,'=',F10.4,/,                              APP06670
     B       1X,29X,'REY75R     ',23X,'=',E10.1,/,                              APP06680
     C       1X,29X,'DIA (FT)   ',23X,'=',F10.4,/,                              APP06690
     D       1X,29X,'P/D        ',23X,'=',F10.4,/,                              APP06700
     E       1X,29X,'AE/AO      ',23X,'=',F10.4,/,                              APP06710
     F       1X,29X,'T/C .75R   ',23X,'=',F10.4,///)                            APP06720
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,          APP06730
     1       1X,29X,'MIN AE/AO',25X,'=',F10.4,/,                                APP06740
     2       1X,29X,'MIN T/C .75R',22X,'=',F10.6)                               APP06750
      END                                                                       APP06760
```

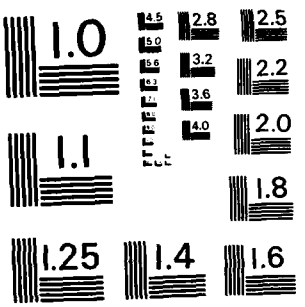
AD-A132 414 PRELIMINARY PROPELLER SELECTION USING THE WAGENINGEN B-SCREW SERIES AND A GENERAL PURPOSE NON-LINEAR OPTIMIZER(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA

4/4

UNCLASSIFIED M P SMITH JUN 83 F/G 13/10 NL



END
DATE FILMED
9 83
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

CONTROL CARD IMAGES--DESIGN CASE NO. 2

```
$A   TITLE
   WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
$B    NCALC      NDV       NSV      N2VAR     NXAPRX     IPNPUT      IPDBG
          2        3                                          0
$C   IPRINT     ITMAX    ICNDIR     NSCAL      ITRM     LINOBJ     NACMX1
          1      100                  -1         30                  15
$D1    FDCH     FDCHM        CT     CTMIN      CTL     CTLMIN      THETA
     0.0001    0.001    -.001
$D2  DELFUN     CABFUN   ALPHAX    ABOBJ1

$E    NDVTOT      ICBJ    SGNOPT
          3         1       1.0
$F       VLB       VUB         X      SCAL
       0.4         1.1       0.40      1.0
      0.01         1.1       0.1       1.0
       0.4         1.4       1.0       1.0
$G   NDSSGN      IDSGN     AMULT
          1         3       1.0
          2        23       1.0
          3         7       1.0
$H    NCONS
         10
$I1    ICON      JCON      LCON
$I2      BL       BU      SCAL2
         11        11
-1.0    +16       1.0       0.0       1.0
         12        12
-1.0    +16       1.0       0.0       1.0
         13        13
-1.0    +16       1.0       0.0       1.0
         14        14
-1.0    +16       1.0       0.0       1.0
         15        15
-1.0    +16       1.0       0.0       1.0
         16        16
-1.0    +16       1.0       0.0       1.0
         17        17
-1.0    +16       1.0       0.0       1.0
         18        18
-1.0    +16       1.0       0.0       1.0
         19        19
-1.0    +16       1.0       0.0       1.0
         21        21
-1.0    +16       1.0       0.0       1.0
$V
END
```

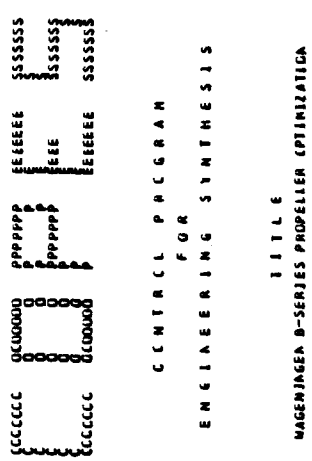
```
$A   TITLE
   WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
$B    NCALC        NDV        NSV      N2VAR     NXAPRX      IPNPUT      IPDBG
                     5                                            0
$C   IPRINT      ITMAX     ICNDIR      NSCAL       ITRM     LINOBJ     NACMX1
            1       1000                 -1         30                    15
$D1     FDCH      FDCHM         CT     CTMIN        CTL     CTLMIN      THETA
        0.0001    0.0001      -.001
$D2  DELFUN     CABFUN     ALPHAX     ABOBJI

$E    NDVTOT       ICBJ     SGNOPT
                     1        1.0
$F       VLB        VUB          X       SCAL
             0.4        1.1        0.40       1.0
            0.01        1.1        0.1        1.0
             0.4        1.4        1.0        1.0
            10.0       10.0       50.0       10.0
           0.003        .5     0.0500       0.01
$G   NDSSGN       IDSGN      AMULT
                     1          3        1.0
                     2         23        1.0
                     3          7        1.0
                     4         10        1.0
                     5          9        1.0
$H    NCONS
                    12
$I1    ICON       JCON       LCON
$I2      BL      SCAL1         BU      SCAL2
                    11                   11
-1.0     +16         1.0        0.0        1.0
                    12                   12
-1.0     +16         1.0        0.0        1.0
                    13                   13
-1.0     +16         1.0        0.0        1.0
                    14                   14
-1.0     +16         1.0        0.0        1.0
                    15                   15
-1.0     +16         1.0        0.0        1.0
                    16                   16
-1.0     +16         1.0        0.0        1.0
                    17                   17
-1.0     +16         1.0        0.0        1.0
                    18                   18
-1.0     +16         1.0        0.0        1.0
                    19                   19
-1.0     +16         1.0        0.0        1.0
                    20                   20
-1.0     +16         1.0        0.0        1.0
```

```
                21              21
-1.0     +16    1.0             0.0             1.0
                22              22
-1.0     +16    1.0             0.0             1.0
$V
END
```

APPENDIX H

COPES OUTPUT--DESIGN CASE NO. 2



CARD IMAGES OF CONTROL DATA

```
CARD                    IMAGE

  1|  $A  TITLE
  2|    'WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
  3|  $E    ACALC      NDV       NSV      N2VAR     NXAPAX     IPNPLT     IPDBG
  4|                      2         3                                0
  5|  $C   IFKIN     ITMAX     ICADIR     NSCAL      ITRM     LINOBJ     NALMAX
  6|                    100          1         -1        30                   15
  7|  $C1    FDCM      FDCHM        CT     CTMIN       CTL    CTLMIN      THETA
  8|     0.0001     0.0001      -.001
  9|  $C2 DELFUN     DABFUN     ALPHAX     ABOBJ1
 10|
 11|
 12|  $E   NCVIOT      IOBJ     SGNOPT
 13|                      1        1.0
 14|  $F      VLB        VUB          X      SCAL
 15|      0.4          1.1        0.40       1.0
 16|     0.01          1.1        0.1        1.0
 17|      0.4          1.4        1.0        1.0
 18|  $G   NCSSGN     IOSGN     APVALT
 19|                      3        1.0
 20|                      2        1.0
 21|                      7        1.0
 22|  $F    XCONS
 23|                     10
 24|  $H    ICON      JCON      LCON
 25|  $I2      BL     SCAL1        BU      SCAL2
 26|                     11
 27|  -1.0    +16         1       0.0       1.0
 28|                     12
 29|  -1.0    +16         1       0.0       1.0
 30|                     13
 31|  -1.0    +16         1       0.0       1.0
 32|                     14
 33|  -1.0    +16         1       0.0       1.0
 34|                     15
 35|  -1.0    +16         1       0.0       1.0
 36|                     16
 37|  -1.0    +16         1       0.0       1.0
 38|                     17
 39|  -1.0    +16         1       0.0       1.0
 40|                     18
 41|  -1.0    +16         1       0.0       1.0
 42|                     19
 43|  -1.0    +16         1       0.0       1.0
 44|                     21
 45|  -1.0    +16       1.0       0.0       1.0
 46|  $E
 47|  EOC
```

```
TITLE:
  WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CONTROL PARAMETERS:
CALCULATION CONTROL,                          NCALC =     4
NUMBER OF GLOBAL DESIGN VARIABLES,            NDV   =     3
NUMBER OF SENSITIVITY VARIABLES,              NSV   =     0
NUMBER OF FUNCTIONS IN TWO-SPACE,             NZVAR =     0
NUMBER OF APPROXIMATION, VAR.                 NZAPRX =    0
INPUT INFORMATION PRINT CODE,                 IPRINP =    0
DEBUG PRINT CODE,                             IPLOG  =    0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     NON-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) =  0.10000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

 IPRINT      ITMAX      ICNSTR      NSCAL      ITRM      LINOBJ      NACMAX      NFDG
      1       1000           0         -1        30           0          15         0

  FDCH                FDCHM               CT                  CTMIN
  0.10000E-03         0.10000E-03         -0.10000E-02        0.0

  CTL                 CTLMIN              THETA               PHI
  0.0                 0.0                 0.0                 0.0

  DELFUN              DABFUN              ALPHAX              ABOBJ1
  0.0                 0.0                 0.0                 0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER          UPPER          INITIAL
NO.        BOUND          BOUND          VALUE          SCALE
  1    0.45000E+00    0.11000E+01    0.40000E+00    0.10000E+01
  2    0.15000E-01    0.11000E+01    0.10000E+00    0.10000E+01
  3    0.45000E+00    0.14000E+01    0.10000E+01    0.10000E+01

DESIGN VARIABLES
       G. V.      GLOBAL      MULTIPLYING
ID      NO.       VAR. NO.      FACTOR
 1        1           3       0.10000E+01
 2        2           4       0.10000E+01
 3        3           5       0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 10 CONSTRAINT SETS
      GLOBAL     GLOBAL     LINEAR          LOWER          NORMALIZATION          UPPER          NORMALIZATION
ID     VAR. 1     VAR. 2       ID           BOUND                FACTOR           BOUND                FACTOR
 1          1          1        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 2          2          2        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 3          3          3        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 4          1          2        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 5          2          3        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 6          1          3        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 7          1          4        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 8          2          4        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
 9          3          4        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01
10          4          4        0     -0.11000E+16     0.10000E+01     0.0          0.10000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS =   10
```

	REAL			INTEGER	
INPUT	EXECUTION	AVAILABLE	INPUT	EXECUTION	AVAILABLE
67	490	10360	43	104	1000

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 2
SUBROUTINE "STALNA"

DESIGN VARIABLES SPECIFIED: QS,A,V,TC75A

ENVIRONMENTAL PARAMETERS:

TEMP (DEG F)	=	64.4000
DENSITY (LBF-SEC2/FT4)	=	1.9902
VISCOSITY (FT2/SEC)	=	0.1[illegible]97E-04
ATMOSPHERIC PRESSURE (PSIA)	=	14.6970
WATER VAPORIZATION PRESSURE (PSIA)	=	0.2564

HULL PARAMETERS:

WAKE FRACTION	=	0.2200
THRUST DEDUCTION FRACTION	=	0.1600
RELATIVE ROTATIVE EFFICIENCY	=	1.0250
NUMBER OF PROPELLERS	=	2.0
DEPTH TO SHAFT CENTERLINE (FT)	=	21.9827
DIAMETER LIMIT (FT)	=	30.0000

PROPELLER PARAMETERS:

NUMBER OF BLADES	=	6.0
MATERIAL TYPE	=	STAINLESS STEEL
ALLOWABLE STRESS (PSI)	=	9400.0

SELECTION VALUES:

PE (HP)	=	57526440.0
V (FT/SEC)	=	31.8682
V (KNOTS)	=	20.0641
VA (KNOTS)	=	17.6500
N (RPM)	=	110.0000
QS (FT-LBF)	=	13101130.0
PD (HP)	=	25344.90
J	=	0.1000
RT	=	0.4001
KQ	=	0.0339
ETAC	=	0.1182
AE/AO	=	0.15610
DIA (FT)	=	14.0937
P/D	=	1.0000
AE/AC	=	0.4000
T/C .75R	=	0.0796

CONSTRAINT VALUES:

MAX DIA (FT)	=	30.0000
MIN AE/AO	=	0.3388
MIN T/C .75R	=	0.062820

```
                    C C O M I N
              FORTRAN PROGRAM FOR
     CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =  -C.118204E+00

DECISION VARIABLES (X-VECTOR)
 1)     C.40000E+00  0.10000E+00  0.10000E+01

CONSTRAINT VALUES (G-VECTOR)
 1)    -C.62500E-01 -0.93736E+00 -0.52026E+03 -0.47874E+03  C.10000E+00 -0.40000E+00
 7)    -C.55696E-01 -0.47757E-01 -0.99946E+00  0.11270E+03
```

```
FINAL OPTIMIZATION INFORMATION
 OBJ =  -0.665992E+00
 DECISION VARIABLES (X-VECTOR)
   1)    0.80177E+00  0.64752E+00  0.90364E+00
 CONSTRAINT VALUES (G-VECTOR)
   1)   -0.44470E+00 -0.29336E+00 -0.24820E+02 -0.97418E+03 -0.30178E+00  0.17773E-02
   7)   -0.15810E-01 -0.87642E-01 -0.24307E-02 -0.36772E+00

 THERE ARE    2 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
      6
      5

 THERE ARE    0 VIOLATED CONSTRAINTS
 THERE ARE    0 ACTIVE SIDE CONSTRAINTS
 TERMINATION CRITERION
      ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR 30 ITERATIONS
 NUMBER OF ITERATIONS =   45
 OBJECTIVE FUNCTION WAS EVALUATED          230  TIMES
 CONSTRAINT FUNCTIONS WERE EVALUATED       230  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 1 FUNCTION VALUE 0.66599E+00

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	3	0.11000E+00	0.80177E+00	0.10000E+01
2	2	24	0.11000E-01	0.64152E+00	0.10000E+01
3	3	7	0.41000E+00	0.90364E+00	0.14000E+01

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.11000E+16	-0.10176E+00	0.0
2	12	-0.11000E+16	-0.35530E+00	0.0
3	13	-0.11000E+16	-0.24871E+00	0.0
4	14	-0.11000E+16	-0.14219E+00	0.0
5	15	-0.11000E+16	-0.46566E-01	0.0
6	16	-0.11000E+16	-0.24871E+00	0.0
7	17	-0.11000E+16	-0.14219E+00	0.0
8	18	-0.11000E+16	-0.46566E-01	0.0
9	19	-0.11000E+16	-0.35530E+00	0.0
10	22	-0.11000E+16	-0.36771E+00	0.0

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 2
SUBROUTINE "STRLNA"

DESIGN VARIABLES SPECIFIED: QS,A,V,TC75R

ENVIRONMENTAL PARAMETERS:

TEMP (DEG F)	=	64.4000
DENSITY (LBF-SEC2/FT4)	=	1.9903
VISCOSITY (FT2/SEC)	=	0.1185999997E-04
ATMOSPHERIC PRESSURE (PSIA)	=	14.6970
WATER VAPORIZATION PRESSURE (PSIA)	=	0.2994

HULL PARAMETERS:

WAKE FRACTION	=	0.2600
THRUST DEDUCTION FRACTION	=	0.1900
RELATIVE ROTATIVE EFFICIENCY	=	1.0250
NUMBER OF PROPELLERS	=	1.0
DEPTH TO SHAFT CENTERLINE (FT)	=	21.9827
DIAMETER LIMIT (FT)	=	30.0000

PROPELLER PARAMETERS:

NUMBER OF BLADES	=	6.0
MATERIAL TYPE	=	STAINLESS STEEL
ALLOWABLE STRESS (PSI)	=	5400.0

SELECTION VALUES:

PE (HP)	=	15057.3
V (FT/SEC)	=	33.8682
V (KNOTS)	=	20.0641
VA (KNOTS)	=	17.6500
N (RPM)	=	117.0000
QS (FT-LBF)	=	1210130.0
PD (HP)	=	25344.90
J	=	0.6475
KT	=	0.1119
KQ	=	0.0266
ETAC	=	0.6460
BETA5R	=	0.5E+08
DIA (FT)	=	22.2533
P/D	=	0.9036
AE/AO	=	0.8018
T/C .75R	=	0.0397

CONSTRAINT VALUES:

MAX DIA (FT)	=	30.0000
MIN AE/AO	=	0.5070
MIN T/C .75R	=	0.021297

PROGRAM CALLS TO ANALYZ

ICALL	CALLS
1	1
2	23
3	2



CENTROL PROGRAM
FOR
ENGINEERING SYNTHESIS

TITLE
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CARD IMAGES OF CONTROL DATA

```
CARD                    IMAGE

 1| $A  TITLE
 2|   'AGENINGEN B-SERIES PROPELLER OPTIMIZATION
 3| $B   NCALC      NGV       NSV      N2VAR     NXAPHX     IPNPLT     IPDBG
 4|            5         3                                      0
 5| $C  IPRINT      ITMAX     ICPDIR    NSCAL     ITHM     LINDEJ     MALMXJ
 6|            1      1000                -1       30                    15
 7| $C1   FDLM      FDCHM        CJ      CTMIN     CTL      CTLMIN     THETA
 8|  0.0001  0.0001  0.0001      .001
 9| $C2 DELFUN    DABFUN    ALPHAX    ABOBJ1
10|
11|
12| $E  NEVTOT      IOBJ     SGNOPT
13|            3         1        1.0
14| $F       VLB       VUB         X      SCAL
15|             0.4         1.1         0.40       1.0
16|            0.01         1.1         0.1        1.0
17|             0.4         1.4         1.0        1.0
18|
19| $G  NCSSGN      IDSGN     APUL
20|             1         3        1.0
21|             2         2        1.0
22|             3         7        1.0
23|
24| $F    ACONS
25|            10
26| $II    ICON      JCEN      ICON
27| $IA      BL      SCAL1        BU      SCAL2
28|             1         1
29|  -1.C    +16         1       0.0         1.0
30|             2         2
31|  -1.C    +16         1       0.0         1.0
32|             3         3
33|  -1.C    +16         1       0.0         1.0
34|             4         4
35|  -1.C    +16         1       0.0         1.0
36|             5         5
37|  -1.C    +16         1       0.0         1.0
38|             6         6
39|  -1.C    +16         1       0.0         1.0
40|             7         7
41|  -1.C    +16         1       0.0         1.0
42|             8         8
43|  -1.0    +16         1       0.0         1.0
44|             9         9
45|  -1.C    +16         1       0.0         1.0
46| $$
47| END
```

```
TITLE:
  MAGENNAGEN B-SERIES PROPELLER OPTIMIZATION


CONTROL PARAMETERS:
CALCULATION CONTROL,                    NCALC =    2
NUMBER OF GLOBAL DESIGN VARIABLES,       NDV =    3
NUMBER OF SENSITIVITY VARIABLES,         NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,      NCVAR =    0
NUMBER OF APPROXIMATION VAR,          NAPPRX =    0
INPUT INFORMATION PRINT CODE,          IPNPUT =    0
DEBUG PRINT CODE,                       IPDBG =    0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWO-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE                =    1
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) =  0.10000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT   ITMAX   ICNDIR   NSCAL   ITER   LINOBJ   NACMAX   NFDG
  1      1000      0       -1      30      0       15       0

FDCH              FDCHM             CT                CTMIN
0.10000E-03       0.10000E-03      -0.10000E-02       0.0

CTL               CTLMIN            THETA             PHI
0.0               0.0               0.0               0.0

DELFUN            DABFUN            ALPHAX            ABOBJ1
0.0               0.0               0.0               0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE NGEOM INPUT
D. V.      LOWER              UPPER              INITIAL
NO.        BOUND              BOUND              VALUE              SCALE
  1     0.45000E+00        0.15000E+01        0.45000E+00        0.10000E+01
  2     0.10000E-01        0.10000E+01        0.10000E+00        0.10000E+01
  3     0.45000E+00        0.15000E+01        0.10000E+01        0.10000E+01

DESIGN VARIABLES
     D. V.      GLOBAL      MULTIPLYING
ID    REF.      VAR. NO.      FACTOR
 1      1          1          0.10000E+01
 2      2          2          0.10000E+01
 3      3          3          0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 10 CONSTRAINT SETS
     GLOBAL   GLOBAL   LINEAR          LOWER          NORMALIZATION          UPPER          NORMALIZATION
ID    VAR. 1   VAR. 2    ID            BOUND             FACTOR              BOUND             FACTOR
 1       1        1        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 2       2        2        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 3       3        3        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 4       4        4        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 5       5        5        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 6       6        6        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 7       7        7        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 8       8        8        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
 9       9        9        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01
10      21       21        0       -0.11000E+16       0.10000E+01        0.0               0.10000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS =   10
```

INPUT #7 HEAT EXECUTION 433 AVAILABLE 10000

INPUT #3 INTERN EXECUTION 104 AVAILABLE 1000

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 2
SUBROUTINE "STRCNA"

DESIGN VARIABLES SPECIFIED: WS,A,V,TC75R

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	65.0000
	DENSITY (LBF-SEC**2/FT4)	=	1.9382
	VISCOSITY (FT2/SEC)	=	0.1409597E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.6973
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2994
HULL PARAMETERS:	WAKE FRACTION	=	0.2600
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH AT SHAFT CENTERLINE (FT)	=	21.9827
	DIAMETER LIMIT (FT)	=	38.3033
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	6.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	2400.0
SELECTED VALUES:	PE (HP)	=	57525.40.0
	V (FT/SEC)	=	32.8882
	VS (KNOTS)	=	20.0641
	VA (KNOTS)	=	17.6540
	N (RPM)	=	117.0000
	QS (FT-LBF)	=	1410130.0
	PD (HP)	=	25344.90
	J	=	0.1000
	KT	=	0.4501
	KQ	=	0.0539
	ETAG	=	0.1102
	RETTSR	=	0.1E+10
	DIA (FT)	=	144.0937
	P/D	=	1.0000
	AE/AO	=	0.4000
	T/C .75R	=	0.0796
CONSTRAINT VALUES:	MAX DIA (FT)	=	36.0000
	MIN AE/AO	=	45.4788
	MIN T/C .75R	=	0.179593

```
        C C A N E N
    FORTRAN PROGRAM FOR
CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =  -0.118204E+00

DECISION VARIABLES (X-VECTOR)
 1)     0.40000E+00  0.10000E+00  0.10000E+01

CONSTRAINT VALUES (G-VECTOR)
 1)    -0.62500E-01 -0.53725E+00 -0.52026E+03 -0.47874E+03  0.10000E+00 -0.40000E+00
 7)    -0.55696E-01 -0.47759E-01 -0.69956E+00  0.12270E+03
```

```
FINAL OPTIMIZATION INFORMATION

OBJ =  -0.665992E+00

DECISION VARIABLES (X-VECTOR)
  X1     0.80177E+00  0.64752E+00  0.50364E+00

CONSTRAINT VALUES (G-VECTOR)
  G1    -0.44470E+00 -0.59536E+00 -0.24820E+02 -0.97518E+03 -0.30178E+00  0.17773E-02
  G7    -0.15810E-01 -0.87642E-01 -0.24307E-02 -0.36772E+00

THERE ARE    2 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
     6     5

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
     ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR 30 ITERATIONS

NUMBER OF ITERATIONS =   45

OBJECTIVE FUNCTION WAS EVALUATED          230  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       230  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 1 FUNCTION VALUE 0.66599E+00

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	3	0.40000E+00	0.80177E+00	0.10000E+01
2	2	23	0.10000E-01	0.64152E+00	0.10000E+01
3	3	7	0.40000E+00	0.90364E+00	0.14000E+01

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.10000E+16	-0.40537E+00	0.0
2	12	-0.10000E+16	-0.59530E+00	0.0
3	13	-0.10000E+16	-0.24811E+02	0.0
4	14	-0.10000E+16	-0.97418E+03	0.0
5	15	-0.10000E+16	-0.30127E+00	0.0
6	16	-0.10000E+16	-0.17248E-02	0.0
7	17	-0.10000E+16	-0.58111E-01	0.0
8	18	-0.10000E+16	-0.57642E-01	0.0
9	19	-0.10000E+16	-0.24527E-02	0.0
10	21	-0.10000E+16	-0.56771E+00	0.0

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 2
SUBROUTINE "STRCNK"

DESIGN VARIABLES SPECIFIED: V,P,D,.75R

ENVIRONMENTAL PARAMETERS:

TEMP (DEG F)	=	64.4000
DENSITY (LBF-SEC2/FT4)	=	1.9892
VISCOSITY (FT2/SEC)	=	0.1189999976-04
ATMOSPHERIC PRESSURE (PSIA)	=	14.6970
WATER VAPORIZATION PRESSURE (PSIA)	=	0.2946

HULL PARAMETERS:

WAKE FRACTION	=	0.2200
THRUST DEDUCTION FRACTION	=	0.1900
RELATIVE ROTATIVE EFFICIENCY	=	1.0250
NUMBER OF PROPELLERS	=	1.00
DEPTH OF SHAFT CENTERLINE (FT)	=	21.9827
DIAMETER LIMIT (FT)	=	32.0300

PROPELLER PARAMETERS:

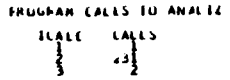
NUMBER OF BLADES	=	6.0
MATERIAL TYPE	=	STAINLESS STEEL
ALLOWABLE STRESS (PSI)	=	5400.0

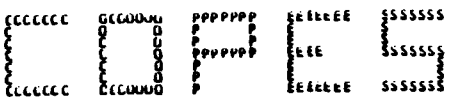
SELECTION VALUES:

PE (HP)	=	14057.3
V (FT/SEC)	=	31.8682
V (KNOTS)	=	20.0643
VA (KNOTS)	=	18.6500
N (RPM)	=	116.0000
QS (FT-LBF)	=	1210132.0
PD (HP)	=	25344.90
J	=	0.6475
KT	=	0.1719
KQ	=	0.0266
ETAG	=	0.6660
AE/AO	=	0.5E+00
DIA (FT)	=	26.2533
P/D	=	0.9036
AE/AO	=	0.8018
T/C .75R	=	0.0397

CONSTRAINT VALUES:

MAX DIA (FT)	=	36.0000
MIN AE/AO	=	0.5070
MIN T/C .75R	=	0.064709


PROGRAM CALLS TO ANALYZ
SCALE
CALLS
1
43
2



CENTRAL PROGRAM
FOR
ENGINEERING SYNTHESIS

TITLE
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CARD IMAGES OF CONTROL DATA

```
CARD                    IMAGE

 1| $A   TITLE
 2|    'AGENING B-SERIES PROPELLER OPTIMIZATION
 3| $B    ACALC       NCV       NSV      N2VAR     NXAPRX     IPNPLT     IPUBG
 4|                     5                                         0
 5| $C   IFRIN      ITMAX     ICADIR     NSCAL     ITRM     LINOBJ     NACMX1
 6|       1         1000                  -1       30                    15
 7| $C1    FULH     FDCHM        CT      CTMIN      CTL     CTLMIN     THETA
 8|    0.0J01    J.0001      -.001
 9| $C2 DELFUN    DABFUN    ALFMAR    ABGBJI
10|
11| $E   NEVTOT      ICBJ    SGNGPT
12|          5         1       1.0
13| $F      VLB       VUB         X      SCAL
14|          0.4       1.          C.40     1.0
15|         0.01       1.          0.1      1.0
16|          0.4       1.          1.0      1.0
17|         10.0     100.0         .0       1.0
18|        C.003       0.5       0.2500     0.01
19| $G   NCSSGN     IDSGN     APDLT
20|          1         3       1.0
21|          2         2       1.0
22|          3         1       1.0
23|          4        10       1.0
24|          5         8       1.0
25| $P    ACONS
26|         12
27| $$$     ICON      JCLN      ICON
28| $$2       BL        BU      SCAL2
29|          11        11
30|  -1.C    +16       1.0       0.0       1.0
31|          12        12
32|  -1.C    +16       1.0       0.0       1.0
33|          13        13
34|  -1.C    +16       1.0       0.0       1.0
35|          14        14
36|  -1.C    +16       1.0       0.0       1.0
37|          15        15
38|  -1.C    +16       1.0       0.0       1.0
39|          16        16
40|  -1.0    +16       1.0       0.0       1.0
41|          17        17
42|  -1.0    +16       1.0       0.0       1.0
43|          18        18
44|  -1.0    +16       1.0       0.0       1.0
45|          19        19
46|  -1.C    +16       1.0       0.0       1.0
47|          20        20
48|  -1.0    +16       1.0       0.0       1.0
49|          21        21
50|  -1.0    +16       1.0       0.0       1.0
51|          22        22
52|  -1.0    +16       1.5       0.0       1.0
53| $$
54| END
```

TITLE:
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CONTROL PARAMETERS:
CALCULATION CONTROL, NCALC = 2
NUMBER OF GLOBAL DESIGN VARIABLES, NDV = 5
NUMBER OF CONSTRAINTS IN TWO-SPACE, N2VAR = 0
NUMBER OF APPROXIMATION VAR, NVAPRX = 0
INPUT INFORMATION PRINT CODE, IPRNTI = 0
DEBUG PRINT CODE, IPDBG = 0

CALCULATION CONTROL, NCALC
VALUE MEANING
1 SINGLE ANALYSIS
2 OPTIMIZATION
3 SENSITIVITY
4 ZERO-VARIABLE FUNCTION SPACE
5 OPTIMUM SENSITIVITY
6 APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.10000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMXI	MFDG
1	1000	0	-1	30	0	15	0

FDCH	FDCHM	CT	CTMIN
0.10000E-03	0.10000E-03	-0.10000E-02	0.0
CTL	CTLMIN	THETA	PHI
5.0	0.0	0.0	0.0
DELFUN	DABFUN	ALPHAX	ABOBJ1
0.0	0.0	0.0	0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	-.10000E+00	0.11000E+01	0.40000E+00	0.10000E+01
2	-.10000E-01	0.13333E+01	0.10000E+00	0.10000E+01
3	-.10000E+00	0.14222E+01	0.10000E+01	0.10000E+01
4	-.10000E+02	0.10000E+03	0.50000E+02	0.10000E+02
5	-.32000E-02	0.50000E+00	0.50000E-01	0.10000E-01

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	3	0.10000E+01
2	2	4	0.10000E+01
3	3	5	0.10000E+01
4	4	10	0.10000E+01
5	5	9	0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 12 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	11	11	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
2	12	12	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
3	13	13	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
4	14	14	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
5	15	15	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
6	16	16	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
7	17	17	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
8	18	18	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
9	19	19	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
10	20	20	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01
11	21	21	0	-0.10000E+16	0.10000E+01	0.0	0.10000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 12

* * ESTIMATED DATA STORAGE REQUIREMENTS

REAL			INTEGER		
INPUT	EXECUTION	AVAILABLE	INPUT	EXECUTION	AVAILABLE
87	270	10000	57	124	1000

OPTIMIZATION RESULTS ----- DESIGN CASE NO. 2
SUBROUTINE "STRCNA"

DESIGN VARIABLES SPECIFIED: QS,A

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	64.4000
	DENSITY (LBF-SEC2/FT4)	=	1.9892
	VISCOSITY (FT2/SEC)	=	0.1169999997E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.6970
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2994
FULL PARAMETERS:	WAKE FRACTION	=	0.2600
	THRUST DEDUCTION FRACTION	=	0.1900
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH AT SHAFT CENTERLINE (FT)	=	21.9627
	DIAMETER LIMIT (FT)	=	30.0000
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	6.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTED VALUES:	PC (FT)	=	**********
	V (FT/SEC)	=	50.0000
	V (KNOTS)	=	29.6208
	VA (KNOTS)	=	22.1042
	N (RPM)	=	110.0000
	TA (FT-LBF)	=	151033.0
	PD (HP)	=	25544.60
	J	=	0.1000
	KT	=	0.4002
	KQ	=	0.0538
	ETAC	=	0.1184
	REY75R	=	0.4E+09
	DIA (FT)	=	212.7212
	P/C	=	1.0000
	AE/AO	=	0.4000
	T/C .75R	=	0.0500
CONSTRAINT VALUES:	MAX DIA (FT)	=	30.0000
	MIN AE/AO	=	103.8435
	MIN T/C .75R	=	0.062794

```
                    C C P M I N
              FORTRAN PROGRAM FOR
     CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =  -0.138442E+00

DECISION VARIABLES (X-VECTOR)
  1)    0.40000E+00  0.10000E+00  0.10000E+01  0.50000E+02  0.50000E-01

CONSTRAINT VALUES (G-VECTOR)
  1)   -0.62500E-01 -0.93750E+00 -0.17864E+04  0.78128E+03  0.10400E+00 -0.40000E+00
  7)   -0.52101E-01 -0.77352E-01 -0.69999E+00  0.60909E+01  0.26661E+03  0.25545E+00
```

```
FINAL OPTIMIZATION INFORMATION

OBJ =  -0.757645E+00

DECISION VARIABLES (X-VECTOR)
  1)    0.754622E+00  0.99270E+00  0.11986E+01  0.52182E+02  0.49512E-01

CONSTRAINT VALUES (G-VECTOR)
  1)   -0.62014E+00 -0.31956E+00 -0.43017E+06 -0.97524E+03 -0.29462E+00 -0.52805E-02
  7)   -0.36014E-01 -0.71434E-01 -0.36016E-03 -0.25451E+00 -0.41625E+03 -0.45777E+00

THERE ARE    2 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
        6         5

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
     ABS((OBJ(I)-OBJ(I-1))/OBJ(I)) LESS THAN DELFUN FOR 30 ITERATIONS
     ABS(CBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR 30 ITERATIONS

NUMBER OF ITERATIONS =   80

OBJECTIVE FUNCTION WAS EVALUATED          544  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       544  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 1 FUNCTION VALUE 0.75764E+00

DESIGN VARIABLES

ID	C. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	24	0.10000E+00	0.19462E+00	0.11000E+01
2	2	23	0.10000E-01	0.99270E+00	0.11000E+01
3	3	7	0.40000E+00	0.11686E+01	0.14000E+01
4	4	10	0.10000E+02	0.52102E+02	0.10000E+03
5	5	9	0.30000E-02	0.49912E-01	0.50000E+00

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.11000E+16	-0.62044E+00	0.0
2	12	-0.11000E+16	-0.37956E+00	0.0
3	13	-0.11000E+16	-0.23077E-02	0.0
4	14	-0.11000E+16	-0.47598E+03	0.0
5	15	-0.11000E+16	-0.55462E+00	0.0
6	16	-0.11000E+16	-0.13826E-02	0.0
7	17	-0.11000E+16	-0.20014E-01	0.0
8	18	-0.11000E+16	-0.17635E-01	0.0
9	19	-0.11000E+16	-0.23633E-03	0.0
10	20	-0.11000E+16	-0.25432E+00	0.0
11	21	-0.11000E+16	-0.41814E+00	0.0
12	22	-0.11000E+16	-0.45778E+00	0.0

OPTIMIZATION RESULTS ----- DESIGN CASE NO. 2
SUBROUTINE "STRLNA"

DESIGN VARIABLES SPECIFIED: WS,A

ENVIRONMENTAL PARAMETERS:

TEMP (DEG F)	=	64.4033
DENSITY (LBF-SEC2/FT4)	=	1.9882
VISCOSITY (FT2/SEC)	=	0.1899999976-04
ATMOSPHERIC PRESSURE (PSIA)	=	14.6970
WATER VAPORIZATION PRESSURE (PSIA)	=	0.2994

HULL PARAMETERS:

WAKE FRACTION	=	0.2200
THRUST DEDUCTION FRACTION	=	0.1900
RELATIVE ROTATIVE EFFICIENCY	=	1.0250
NUMBER OF PROPELLERS	=	1.0
DEPTH TO SHAFT CENTERLINE (FT)	=	21.9827
DIAMETER LIMIT (FT)	=	30.3000

PROPELLER PARAMETERS:

NUMBER OF BLADES	=	6.0
MATERIAL TYPE	=	STAINLESS STEEL
ALLOWABLE STRESS (PSI)	=	5400.3

SELECTION VALUES:

PE (HP)	=	15945.5
V (FT/SEC)	=	35.1824
V (KNOTS)	=	20.8138
VA (KNOTS)	=	24.1127
N (RPM)	=	110.3000
WS (FT-LBF)	=	1.0130.0
PD (HP)	=	25344.90
J	=	0.5927
KT	=	0.1552
KQ	=	0.0324
ETAC	=	0.7576
REYTOR	=	0.5E+08
DIA (FT)	=	22.3645
P/D	=	1.1986
AE/AC	=	0.1546
T/C .75R	=	0.0499

CONSTRAINT VALUES:

MAX W/A (FT)	=	30.0000
MIN AE/AO	=	0.4622
MIN T/C .75R	=	0.027064

PROGRAM CALLS TO ANALYZ

ICALL	CALLS
1	1
2	545
3	2



CENTRAL PROGRAM
FOR
ENGINEERING SYNTHESIS

TITLE
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CARD IMAGES OF CONTROL DATA

```
CARD                    IMAGE

 1| $A  TITLE
 2|    'AGENING-EN B-SERIES PROPELLER OPTIMIZATION
 3| $E    NCALC       NDV       NSV      N2VAR    NXAPRX     IPNPLT     IPDBG
 4|                     5                                         0
 5| $C  IPRINT      ITMAX     ICNDIR     NSCAL     ITRM     LINOBJ    NACMAX
 6|        1         1000                  -1       30        CTL    CTLMIN       15
 7| $E1    FUCM     FDCHM         CT     CTMIN
 8|   0.0001    0.0001      -.001
 9| $E2 DELFUN     DABFUN    ALPMAX     ABOBJ1
10|
11|
12| $E  NLVTOT      ITOBJ     SGPROPT
13|        5          1         1.0
14| $F      VLB       VUB         X      SCAL
15|        0.4         1.        1.0       1.0
16|       0.01         1.        1.0       1.0
17|        0.4         1.        1.0       1.0
18|       10.0       100.       10.0      10.0
19|      C.003        0.5      0.250      0.01
20| $E  NCSSGN      IDSGN     ABULT
21|          1          1       1.0
22|          2          2       1.0
23|          3          3       1.0
24|          4         10       1.0
25|          5          9       1.0
26| $F   ACONS
27|         12
28| $$$   ICON      JCON      ICON
29| $$$     BL     SCALI        BU     SCAL2
30|   -1.0   +16        1       0.0       1.0
31|                     12
32|   -1.0   +16        1       0.0       1.0
33|                     13
34|   -1.0   +16        1       0.0       1.0
35|                     14
36|   -1.0   +16        1       0.0       1.0
37|                     15
38|   -1.0   +16        1       0.0       1.0
39|                     16
40|   -1.0   +16        1       0.0       1.0
41|                     17
42|   -1.0   +16        1       0.0       1.0
43|                     18
44|   -1.0   +16        1       0.0       1.0
45|                     19
46|   -1.0   +16        1       0.0       1.0
47|                     20
48|   -1.0   +16        1       0.0       1.0
49|                     21
50|   -1.0   +16        1       0.0       1.0
51|                     22
52|   -1.0   +16        1       0.0       1.0
53| $$$
54| END
```

TITLE:
MAGENDANZA B-SERIES PROPELLER OPTIMIZATION

CONTROL PARAMETERS:

CALCULATION CONTROL.	NCALC =	2
NUMBER OF GLOBAL DESIGN VARIABLES.	NDV =	5
NUMBER OF SENSITIVITY VARIABLES.	NSV =	0
NUMBER OF PLOTTING IN TWO-SPACE.	NGVAR =	0
NUMBER OF APPROXIMATING VAR.	NAPPR =	0
INPUT INFORMATION PRINT CODE.	IPNPUT =	0
DEBUG PRINT CODE.	IPDBG =	0

CALCULATION CONTROL, NCALC

VALUE	MEANING
1	SINGLE ANALYSIS
2	OPTIMIZATION
3	SENSITIVITY
4	TWO-VARIABLE FUNCTION SPACE
5	OPTIMUM SENSITIVITY
6	APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 1
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.10000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1	NFDG
1	ICOD	0	-1	30	0	15	0

FDCH	FDCHM	CT	CTMIN
0.10000E-03	0.10000E-03	0.0	0.0
CTL	CTLMIN	THETA	PHI
0.0	0.0	0.0	0.0
DELFUN	DABFUN	ALPHAX	ABOBJ1
0.0	0.0	0.0	0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.12000E+00	0.11000E+01	0.30000E+00	0.10000E+01
2	0.12000E+01	0.50000E+02	0.30000E+02	0.10000E+02
3	0.0	0.10000E+08	0.10000E+00	0.10000E+01
4	0.50000E+00	0.15000E+01	0.90000E+00	0.10000E+01
5	0.32000E-02	0.50000E+00	0.30000E-01	0.10000E-01

DESIGN VARIABLES

ID	L. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	3	0.10000E+01
2	2	4	0.10000E+01
3	3	23	0.10000E+01
4	4	7	0.10000E+01
5	5	9	0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 12 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	11	12	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
2	12	13	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
3	13	14	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
4	14	15	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
5	15	16	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
6	16	17	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
7	17	18	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
8	18	19	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
9	19	20	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
10	20	21	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01
11	21	21	0	-0.11000E+16	0.10000E+01	0.0	0.10000E+01

OPTIMIZATION RESULTS ----- DESIGN CASE NO. 2
SUBROUTINE "STRCNK"

DESIGN VARIABLES SPECIFIED: QS,A

ENVIRONMENTAL PARAMETERS:

TEMP (DEG F)	=	64.4000
DENSITY (LBF-SEC2/FT4)	=	1.9892
VISCOSITY (FT2/SEC)	=	0.1189999976-04
ATMOSPHERIC PRESSURE (PSIA)	=	14.6970
WATER VAPORIZATION PRESSURE (PSIA)	=	0.2994

FULL PARAMETERS:

WAKE FRACTION	=	0.2200
THRUST DEDUCTION FRACTION	=	0.1900
RELATIVE ROTATIVE EFFICIENCY	=	1.0250
NUMBER OF PROPELLERS	=	1.0
DEPTH TO SHAFT CENTERLINE (FT)	=	21.9827
DIAMETER LIMIT (FT)	=	50.0000

PROPELLER PARAMETERS:

NUMBER OF BLADES	=	4.0
MATERIAL TYPE	=	STAINLESS STEEL
ALLOWABLE STRESS (PSI)	=	5400.0

SELECTION VALUES:

PE (HP)	=	**********
V (FT/SEC)	=	50.0000
V (KNOTS)	=	29.6298
VA (KNOTS)	=	23.1042
N (RPM)	=	110.0000
QS (FT-LBF)	=	10130.0
PD (HP)	=	25344.90
J	=	0.1000
KT	=	0.4002
KQ	=	0.0538
ETAC	=	0.1184
REY75R	=	0.5E+10
DIA (FT)	=	21.7272
P/D	=	1.0000
AE/AO	=	0.4000
T/C .75R	=	0.0500

CONSTRAINT VALUES:

MAX DIA (FT)	=	30.0000
MIN AE/AO	=	0.1
MIN T/C .75R	=	0.0

C L A M I N

FORTRAN PROGRAM FOR

CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ = -C.118442E+0C

DECISION VARIABLES (X-VECTOR)

11	C.4C030E+00	0.10000E+00	0.10000E+01	0.50000E+02	0.50000E-01

CONSTRAINT VALUES (G-VECTOR)

11	-C.62500E-01	-0.93750E+00	-0.17803E+04	0.78125E+03	C.10000E+00	-0.99999E+00
11	-C.3C103E-01	-0.77352E-01	-0.64995E+00	0.60900E+01	C.26801E+03	0.25919E+01

```
FINAL OPTIMIZATION INFORMATION

 OBJ =  -6.722977E+00

 DECISION VARIABLES (X-VECTOR)
   1)     6.76850E+00  0.87525E+00  0.10306E+01  0.49856E+02  0.63638E-01

 CONSTRAINT VALUES (G-VECTOR)
   1)    -6.54704E+00 -0.43279E+00 -0.22931E+02 -0.97645E+03 -6.29629E+00 -0.14130E-01
   7)    -2.43940E-01 -0.63513E-01 -0.66166E-01 -0.19217E+00 -0.46566E+00  0.45176E-03

 THERE ARE    2 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
      8    12

 THERE ARE    0 VIOLATED CONSTRAINTS

 THERE ARE    0 ACTIVE SIDE CONSTRAINTS

 TERMINATION CRITERION
      ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR 30 ITERATIONS

 NUMBER OF ITERATIONS =   35

 OBJECTIVE FUNCTION WAS EVALUATED          209  TIMES

 CONSTRAINT FUNCTIONS WERE EVALUATED       209  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL EQUATION 1 FUNCTION VALUE 0.7[illegible]E+00

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	3	0.1[illegible]E+00	0.79858E+00	0.1[illegible]E+01
2	2	4	0.1[illegible]E-01	0.87525E+00	0.1[illegible]E+01
3	3	7	0.1[illegible]E+00	0.10308E+01	0.1[illegible]E+01
4	4	10	0.1[illegible]E+02	0.49856E+02	0.1[illegible]E+03
5	5	9	0.3[illegible]E-02	0.63038E-01	0.3[illegible]E+00

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.1[illegible]E+16	-0.54763E+00	0.0
2	12	-0.1[illegible]E+16	-0.[illegible]E+00	0.0
3	13	-0.1[illegible]E+16	-0.[illegible]E+02	0.0
4	14	-0.1[illegible]E+16	-0.[illegible]E+03	0.0
5	15	-0.1[illegible]E+16	-0.[illegible]E+00	0.0
6	16	-0.1[illegible]E+16	-0.[illegible]E-12	0.0
7	17	-0.1[illegible]E+16	-0.[illegible]E-11	0.0
8	18	-0.1[illegible]E+16	-0.[illegible]E-01	0.0
9	19	-0.1[illegible]E+16	-0.[illegible]E-01	0.0
10	20	-0.1[illegible]E+16	-0.[illegible]E+00	0.0
11	21	-0.1[illegible]E+16	-0.[illegible]E+00	0.0
12	22	-0.1[illegible]E+16	0.46730E-03	0.0

OPTIMIZATION RESULTS ----- DESIGN CASE NO. 2
SUBROUTINE "STRLNK"

DESIGN VARIABLES SPECIFIED: US,A

ENVIRONMENTAL PARAMETERS:

TEMP (DEG F)	=	64.4000
DENSITY (LBF-SEC2/FT4)	=	1.9892
VISCOSITY (FT2/SEC)	=	0.1189999973E-04
ATMOSPHERIC PRESSURE (PSIA)	=	14.6970
WATER VAPORIZATION PRESSURE (PSIA)	=	0.2994

HULL PARAMETERS:

WAKE FRACTION	=	0.2200
THRUST DEDUCTION FRACTION	=	0.1900
RELATIVE ROTATIVE EFFICIENCY	=	1.0250
NUMBER OF PROPELLERS	=	1.0
DEPTH TO SHAFT CENTERLINE (FT)	=	21.9827
DIAMETER LIMIT (FT)	=	30.0000

PROPELLER PARAMETERS:

NUMBER OF BLADES	=	6.0
MATERIAL TYPE	=	STAINLESS STEEL
ALLOWABLE STRESS (PSI)	=	5400.0

SELECTION VALUES:

PE (HP)	=	26653.7
V (FT/SEC)	=	45.8560
V (KNOTS)	=	26.5355
VA (KNOTS)	=	22.0371
N (RPM)	=	110.0000
QS (FT-LBF)	=	1410130.0
PD (HP)	=	25544.90
J	=	0.8753
KT	=	0.1220
KQ	=	0.0232
ETAC	=	0.7330
RETA75R	=	0.6E+08
DIA (FT)	=	24.2346
P/C	=	1.0308
AE/AO	=	0.7986
T/C .75R	=	0.0638

CONSTRAINT VALUES:

MAX DIA (FT)	=	30.0000
MIN AE/AO	=	0.4266
MIN T/C .75R	=	0.063868

PROGRAM CALLS TO ANALYZ

ICALC	CALLS
1	1
2	10
3	2

```
      SUBROUTINE ANALIZ(ICALC)                                                  APPOOC010
      INTEGER*4 ICALC                                                           APPOOC020
      REAL*4 ETAO,WEIGHT,AEDVAD,DIA,N,PE,FDIVD,QS,TC75R,V,                      APPOOC030
     1       RJCNL,RJCNU,R75RCL,R75RCU,AEAOCL,AEACCU,TC75CL,TC75CU,             APPOOC040
     2       POWBAL,DIACNU,AEAOCV,TCSTRS,RJ,                                    APPOOC050
     3       VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,                       APPOOC060
     4       PWATVA,PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC,                       APPOOC070
     5       C75R,R75R,KT,KC,PD,TDEV,PTDEV,PECEV,CREC,PDREQ                     APPOOC080
      COMMON /GLOBCM/ETAO,WEIGHT,AEDVAD,DIA,N,PE,FDIVD,QS,TC75R,V,RJCNL,        APPOOC090
     1RJCNU,R75RCL,R75RCU,AEAOCL,AEAOCU,TC75CL,TC75CU,POWBAL,DIACNU,            APPOOC100
     2AEACCV,TCSTRS,RJ                                                          APPOOC110
      COMMON /PARAM/VK,TC,WT,Z,WATRO,WATNU,TEMP,NCSCRW,HCL,PATM,PWATVA,         APPOOC120
     1PROMAT,DIALIM,ETARR,AEAOMN,TC75MN,SC                                      APPOOC130
C                                                                               APPOOC140
C     THIS SUBROUTINE, COUPLED WITH COPES/CONMIN, CONSTITUTES ANALYSIS          APPOOC150
C     METHOD FOR "DESIGN CASE 3" PROPELLER SELECTION PROBLEMS                   APPOOC160
C                                                                               APPOOC170
C     INPUT-INITIALIZATION PHASE                                                APPOOC180
C                                                                               APPOOC190
      PII=3.14159264                                                            APPOOC200
      IF(.NOT.(ICALC.EQ.1))GO TO 1                                              APPOOC210
C                                                                               APPOOC220
CCC         SET "DESIGN CASE 3" PARAMETERS                                      APPOOC230
CCC                                                                             APPOOC240
CCC         ENVIRONMENTAL                                                       APPOOC250
C                                                                               APPOOC260
            TEMP=59.0                                                           APPOOC270
            WATRO=1.9905                                                        APPOOC280
            WATNU=.000012817                                                    APPOOC290
            PATM=14.7                                                           APPOOC300
            PWATVA=.247                                                         APPOOC310
C                                                                               APPOOC320
CC          PROPELLER PARAMETERS                                                APPOOC330
CC                                                                              APPOOC340
            Z=6.0                                                               APPOOC350
            PROMAT=5.0                                                          APPOOC360
C                                                                               APPOOC370
CC          HULL PARAMETERS                                                     APPOOC380
CC                                                                              APPOOC390
            WT=0.22                                                             APPOOC400
            TC=0.1125                                                           APPOOC410
            ETARR=1.025                                                         APPOOC420
            NCSCRW=1.0                                                          APPOOC430
            HCL=19.0                                                            APPOOC440
C                                                                               APPOOC450
CC          SET DESIGN VARIABLES HELD FIXED FOR "DESIGN CASE 3"                 APPOOC460
CC                                                                              APPOOC470
            PE=21252.6                                                          APPOOC480
```

```
      VK=24.24                                                          APPOC490
      V=1.688*VK                                                        APPOC500
      N=105.0                                                           APPOC510
      QS=150C606.75                                                     APPOC520
      DIA=22.0                                                          APPOC530
C                                                                       APPOC540
CC    END OF INPUT-INITIALIZATION PHASE                                 APPOC550
CC                                                                      APPOC560
CC                                                                      APPOC570
      GO TO 3                                                           APPOC580
C                                                                       APPOC590
C     EXECUTION PHASE                                                   APPOC600
C                                                                       APPOC610
    1 CONTINUE                                                          APPOC620
      IF(.NOT.(ICALC.EQ.2))GO TO 2                                      APPOC630
      CALL R_CAL(RJ)                                                    APPOC640
      CALL C75RA(C75R)                                                  APPOC650
      CALL REY75R(C75R,R75R)                                            APPOC660
      CALL CCEFSA(RJ,R75R,KT,KQ)                                        APPOC670
      CALL OPWEFF(RJ,KT,KQ,ETAO)                                        APPOC680
      CALL JCNA(RJ,RJCAL,RJCNU)                                         APPOC690
      CALL REYCNA(R75R,R75RCL,R75RCU)                                   APPOC700
      CALL EXTCCN(Z,AEOVAO,TC75R,AEAOCL,AEAOCU,TC75CL,TC75CU)           APPOC710
      CALL BLPOW3(KT,KQ,POWBAL,DIACAL)                                  APPOC720
      CALL CAVCNA(KT,AEAOCV)                                            APPOC730
      CALL STRCNK(KC,KT,C75R,TCSTRS)                                    APPOC740
      CALL WGTCAL(C75R)                                                 APPOC750
CC                                                                      APPOC760
CC    END OF EXECUTION PHASE                                            APPOC770
CC                                                                      APPOC780
      GO TO 3                                                           APPOC790
    2 CONTINUE                                                          APPOC800
C                                                                       APPOC810
C     OUTPUT-RESULT PHASE                                               APPOC820
C                                                                       APPOC830
      PD=(2.0*PII*QS*N)/33000.0                                         APPOC840
      TQEV=(KT*WATRO*(DIA**4)*((N/60.0)**2))                            APPOC850
      PTQEV=(TQEV*((1.0-WT)*V))/550.0                                   APPOC860
      PEQEV=((((1.0-TD)/(1.0-WT))*ETARR*PTQEV)*NOSCRW)                  APPOC870
      QREQ=(KQ*WATRO*(DIA**5)*((N/60.0)**2))                            APPOC880
      PDREQ=(2.0*PII*QREQ*N)/33000.0                                    APPOC890
      ETAQSP=(((1.0-WT)/(1.0-TD))*(((PE/NOSCRW)*33000.0)/ETARR))/       APPOC900
     1        (2.0*PII*QS*N)                                           APPOC910
      WRITE(6,9000)                                                     APPOC920
      WRITE(6,9001)                                                     APPOC930
      WRITE(6,9002)TEMP,WATRO,WAINU,PATM,PWAIVA                         APPOC940
      WRITE(6,9003)WT,TD,ETARR,NOSCRW,HCL,DIALIM                        APPOC950
      WRITE(6,9004)Z                                                    APPOC960
      IF(.NOT.(PROMAT.EQ.1.0))GO TO 81
```

```
            WRITE(6,9005)SC                                                     APP0C570
          GC TO 86                                                              APP0C980
   81     CONTINUE                                                              APP0C990
          IF(.NOT.(PROMAT.EQ.2.0))GC TO 82                                      APP01000
            WRITE(6,9006)SC                                                     APP01010
          GC TO 86                                                              APP01020
   82     CONTINUE                                                              APP01030
          IF(.NOT.(PROMAT.EQ.3.0))GC TO 83                                      APP01040
            WRITE(6,9007)SC                                                     APP01050
          GC TO 86                                                              APP01060
   83     CONTINUE                                                              APP01070
          IF(.NOT.(PROMAT.EQ.4.0))GC TO 84                                      APP01080
            WRITE(6,9008)SC                                                     APP01090
          GC TO 86                                                              APP01100
   84     CONTINUE                                                              APP01110
          IF(.NOT.(PROMAT.EQ.5.0))GC TO 85                                      APP01120
            WRITE(6,9009)SC                                                     APP01130
          GC TO 86                                                              APP01140
   85     CONTINUE                                                              APP01150
            WRITE(6,9010)                                                       APP01160
   86     CONTINUE                                                              APP01170
          WRITE(6,9011)PE,V,N,QS,PD,ETACSP,RJ,KT,KQ,ETAO,K75K,DIA,              APP01180
     1                 PDIVC,AEDVAO,TC75R,WEIGHT                              APP01190
          WRITE(6,9012)DIALIM,AEAOMN,TC75MN                                     APP01200
          WRITE(6,9013)PEDEV,VK,QREC,N,PCREC                                    APP01210
    3 CONTINUE                                                                  APP01220
      RETURN                                                                    APP01230
                                                                                APP01240
C     MISCELLANEOUS FORMAT STATEMENTS                                           APP01250
C                                                                               APP01260
 9000 FORMAT('1','OPTIMIZATION RESULTS ------- DESIGN CASE NO. 3',/            APP01270
     1       1X,'                                SUBROUTINE "STRCNK"',///)      APP01280
 9001 FORMAT(1X,'DESIGN VARIABLES SPECIFIED:  PE,V,QS,N,DIA',/)                 APP01290
 9002 FORMAT(1X,'ENVIRONMENTAL PARAMETERS:    TEMP (DEG F)',22X,'=',           APP01300
     1       F10.4,/,                                                           APP01310
     1       1X,29X,'DENSITY (LBF-SEC2/FT4)',12X,'=',F10.4,/,                   APP01320
     2       1X,29X,'VISCOSITY (FT2/SEC)',15X,'=',E16.9,/,                      APP01330
     3       1X,29X,'ATMOSPHERIC PRESSURE (PSIA)',7X,'=',F10.4,/,               APP01340
     4       1X,29X,'WATER VAPORIZATION PRESSURE (PSIA)=',F10.4,//)             APP01350
 9003 FORMAT(1X,'FULL PARAMETERS:',13X,'WAKE FRACTION',21X,'=',F10.4,/,         APP01360
     1       1X,29X,'THRUST DEDUCTION FRACTION',9X,'=',F10.4,/,                 APP01370
     2       1X,29X,'RELATIVE ROTATIVE EFFICIENCY',6X,'=',F10.4,/,              APP01380
     3       1X,29X,'NUMBER OF PROPELLERS',14X,'=',F10.1,/,                     APP01390
     4       1X,29X,'DEPTH TO SHAFT CENTERLINE (FT)',4X,'=',F10.4,/,            APP01400
     5       1X,29X,'DIAMETER LIMIT (FT)',15X,'=',F10.4,//)                     APP01410
 9004 FORMAT(1X,'PROPELLER PARAMETERS:',8X,'NUMBER OF BLADES',18X,'=',          APP01420
     1       F10.1)                                                             APP01430
 9005 FORMAT(1X,29X,'MATERIAL TYPE',21X,'=  CAST IRON',/,                       APP01440
```

```
     1          1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP01450
9006 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  CAST STEEL',/,                        APP01460
     1          1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP01470
9007 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  BRONZE',/,                            APP01480
     1          1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP01490
9008 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NI-AL BRONZE',/,                      APP01500
     1          1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP01510
9009 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  STAINLESS STEEL',/,                   APP01520
     1          1X,25X,'ALLOWABLE STRESS (PSI)',12X,'=',F10.1,/)                  APP01530
9010 FORMAT(1X,25X,'MATERIAL TYPE',21X,'=  NOT CONSIDERED',/)                    APP01540
9011 FORMAT(1X,'SELECTION VALUES:',12X,'PE (HP)',27X,'=',F10.1,/,                APP01550
     2          1X,25X,'V  (FT/SEC)',23X,'=',F10.4,/,                           APP01560
     3          1X,25X,'N  (RPM)   ',23X,'=',F10.4,/,                           APP01570
     4          1X,25X,'CS (FT-LBF)',23X,'=',F12.1,/,                           APP01580
     5          1X,25X,'PD  (HP)   ',23X,'=',F10.2,//,                          APP01590
     6          1X,25X,'ETAC SPECIFIED',20X,'=',F10.4,//,                       APP01600
     7          1X,25X,'J          ',23X,'=',F10.4,/,                           APP01610
     8          1X,25X,'KT         ',23X,'=',F10.4,/,                           APP01620
     9          1X,25X,'KQ         ',23X,'=',F10.4,/,                           APP01630
     A          1X,25X,'ETAC       ',23X,'=',F10.4,/,                           APP01640
     B          1X,25X,'REY75R     ',23X,'=',E10.1,/,                           APP01650
     C          1X,25X,'CIA (FT)   ',23X,'=',F10.4,/,                           APP01660
     D          1X,25X,'P/D        ',23X,'=',F10.4,/,                           APP01670
     E          1X,25X,'AE/AO      ',23X,'=',F10.4,/,                           APP01680
     F          1X,25X,'T/C .75R   ',23X,'=',F10.4,/,                           APP01690
     G          1X,25X,'BLADE WEIGHT (LBF)',16X,'=',F10.1,//)                   APP01700
9012 FORMAT(1X,'CONSTRAINT VALUES:',11X,'MAX DIA (FT)',22X,'=',F10.4,/,          APP01710
     1          1X,25X,'MIN AE/AO',25X,'=',F10.4,/,                             APP01720
     2          1X,25X,'MIN T/C .75R',22X,'=',F10.6,///)                        APP01730
9013 FORMAT(1X,'PROPELLER "POINTS":',10X,'PE DEVELOPED (HP)',17X,'=',            APP01740
     F10.1,/,                                                                    APP01750
     1          1X,25X,'V  (KNOTS) ',23X,'=',F10.4,//,                          APP01760
     2          1X,25X,'CS REQUIRED (FT-LBF)',14X,'=',F12.1,/,                  APP01770
     3          1X,25X,'N  (RPM)   ',23X,'=',F10.4,/,                           APP01780
     4          1X,25X,'PD REQUIRED (HP)',18X,'=',F10.2,/////)                  APP01790
      END                                                                        APP01800
```

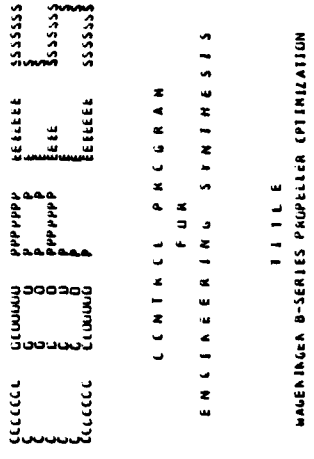
CONTROL CARD IMAGES--DESIGN CASE NO. 3

```
$A   TITLE
  WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
$B    NCALC      NDV      NSV     N2VAR    NXAPRX    IPNPUT    IPDBG
          2        3                                       0
$C   IPRINT    ITMAX   ICNDIR     NSCAL      ITRM    LINOBJ   NACMX1
          1     1000                -1         30                15
$D1    FDCH    FDCHM       CT     CTMIN       CTL    CTLMIN     THETA
      .001     .001     -.01
$D2  DELFUN   CABFUN   ALPHAX   ABOBJI
$E   NDVTOT     IOBJ   SGNOPT
         3        2     -1.0
$F       VLB      VUB        X      SCAL
         0.2      1.1     1.00       1.0
         0.4      1.4      1.3       1.0
       0.003      0.5   0.0100     0.100
$G   NDSGN    IDSGN    AMULT
         1        3      1.0
         2        7      1.0
         3        9      1.0
$H    NCONS
        12
$I1    ICON     JCON     LCON
$I2      BL    SCAL1       BU    SCAL2
         11       11
-1.0    +16       12      1.0      0.0      1.0
-1.0    +16       13      1.0      0.0      1.0
-1.0    +16       14      1.0      0.0      1.0
-1.0    +16       15      1.0      0.0      1.0
-1.0    +16       16      1.0      0.0      1.0
-1.0    +16       17      1.0      0.0      1.0
-1.0    +16       18      1.0      0.0      1.0
-1.0    +16       19      1.0      0.0      1.0
-1.0    +16       20      1.0      0.0      1.0
-1.0    +16       21      1.0      0.0      1.0
-1.0    +16       22      1.0      0.0      1.0
```

$V
END

APPENDIX K

COPES OUTPUT--DESIGN CASE NO. 3



CARD IMAGES IN CONTROL DATA

```
CARD                    IMAGE

 1  $A  TITLE
 2    PACENGINEEN B-SERIES PROPELLER OPTIMIZATION
 3  $E     PCALC      NCV       NSV      N2VAR     NAAPRX     IPNPLT     IPDDG
 4                      3                                          0
 5  $C   IFRIN1     ITMAX     ICADJR     NSCAL      ITRM     CINDEX     MAGMAX
 6                   1000                 -1        30                    15
 7  $C1     FDLM     FDCRM         CI     CIMIN      CTL     CILMIN      THETA
 8           .004      .001      -.01
 9  $C2 DEEFUN     DABFUN     ALPMAX     ABOBJI
10
11
12  $E   NCVIOI       IOBJ     SGNOPT
13                       2       -1.0
14  $F       VLO       VUB         X      SCAL
15               0.2       1.1      1.00      1.0
16               0.4       1.4       1.3      1.0
17             0.005       0.5    0.0100    0.100
18  $C   NDESGN      IDSGN      APDLT
19                1         3       1.0
20                2         7       1.0
21                3         9       1.0
22  $F    NCONS
23                12
24  $11     ICON      JCON       ICON
25  $12       NL    SCALI        BU      SCAL2
26                11        11
27  -1.0    +16       1.0        12       0.0       1.0
28  -1.0    +16       1.0        13       0.0       1.0
29  -1.0    +16       1.0        14       0.0       1.0
30  -1.0    +16       1.0        15       0.0       1.0
31  -1.0    +16       1.0        16       0.0       1.0
32  -1.0    +16       1.0        17       0.0       1.0
33  -1.0    +16       1.0        18       0.0       1.0
34  -1.0    +16       1.0        19       0.0       1.0
35  -1.0    +16       1.0        20       0.0       1.0
36  -1.0    +16       1.0        21       0.0       1.0
37  -1.0    +16       1.0        22       0.0       1.0
38  $1
39  END
```

TITLE:
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

CONTROL PARAMETERS:
CALCULATION CONTROL, NCALC = 4
NUMBER OF GLOBAL DESIGN VARIABLES, NDV = 3
NUMBER OF SENSITIVITY VARIABLES, NSV = 0
NUMBER OF FUNCTIONS IN TWO-SPACE, NZVAR = 0
NUMBER OF APPROXIMATING VAR., NXAPRX = 0
INPUT INFORMATION PRINT CODE, IPRINT = 0
DEBUG PRINT CODE, IPDBG = 0

CALCULATION CONTROL, NCALC
VALUE MEANING
1 SINGLE ANALYSIS
2 OPTIMIZATION
3 SENSITIVITY
4 TWO-VARIABLE FUNCTION SPACE
5 OPTIMUM SENSITIVITY
6 APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 2
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = -0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	IITM	LINOBJ	NACMXI	NFDG
1	100	0	-1	30	0	15	0

FDCH	FDCHM	CT	CTMIN
0.1000E-02	0.1000E-02	-0.1000E-01	0.0

CTL	CTLMIN	THETA	PHI
0.0	0.0	0.0	0.0

DELFUN	DABFUN	ALPHAX	ABOBJ1
0.0	0.0	0.0	0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.2000E+00	0.1100E+01	0.1000E+01	0.1000E+01
2	0.4000E+00	0.1400E+01	0.1300E+01	0.1000E+01
3	0.3000E-02	0.5000E+00	0.1000E-01	0.1000E+00

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	3	0.1000E+01
2	2	7	0.1000E+01
3	3	9	0.1000E+01

CONSTRAINT INFORMATION

THERE ARE 12 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	11	11	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
2	12	12	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
3	13	13	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
4	14	14	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
5	15	15	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
6	16	16	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
7	17	17	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
8	18	18	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
9	19	19	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
10	20	20	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
11	21	21	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01
12	22	22	0	-0.1100E+16	0.1000E+01	0.0	0.1000E+01

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 12

* * ESTIMATED DATA STORAGE REQUIREMENTS

REAL			INTEGER		
INPUT	EXECUTION	AVAILABLE	INPUT	EXECUTION	AVAILABLE
72	504	10000	49	112	1000

OPTIMIZATION RESULTS -------	DESIGN CASE NO. 3 SUBROUTINE "STRCNK"		
DESIGN VARIABLES SPECIFIED:	PE,V,QS,N,DIA		
ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	55.0000
	DENSITY (LBF-SEC2/FT4)	=	1.9905
	VISCOSITY (FT2/SEC)	=	0.1281703704E-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2260
	THRUST DEDUCTION FRACTION	=	0.1725
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	0.0
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	6.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTION VALUES:	PE (HP)	=	21292.6
	V (FT/SEC)	=	40.9121
	N (RPM)	=	105.0000
	QS (FT-LBF)	=	1200607.0
	PD (HP)	=	30000.05
	ETAC SPECIFIED	=	0.6527
	J	=	0.8290
	KT	=	0.2980
	KQ	=	0.0397
	ETAC	=	0.6585
	REY75R	=	0.8E+08
	DIA (FT)	=	22.5000
	P/D	=	1.3000
	AE/AO	=	1.0000
	T/C .75R	=	0.0100
	BLADE WEIGHT (LBF)	=	2563.1
CONSTRAINT VALUES:	MAX CLA (FT)	=	0.0
	MIN AE/AO	=	1.0266
	MIN T/C .75R	=	0.034838
PROPELLER "POINTS":	PE DEVELOPED (HP)	=	24856.6
	V (KNOTS)	=	24.2400
	QS REQUIRED (FT-LBF)	=	1175936.0
	N (RPM)	=	105.0000
	PD REQUIRED (HP)	=	37503.62

```
                    C C P M I N
              FORTRAN PROGRAM FOR
     CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =  0.256313E+04

DECISION VARIABLES (X-VECTOR)
  1)    0.10000E+01  0.13000E+01  0.10000E-01

CONSTRAINT VALUES (G-VECTOR)
  1)   -0.51811E+00 -0.48185E+00 -0.36758E+02 -0.98224E+03 -0.50000E+00  0.20000E+00
  7)    0.99987E-02 -0.24470E+00 -0.26131E+00  0.25012E+00  0.26567E-01  0.44838E+01
```

```
FINAL OPTIMIZATION INFORMATION

OBJ =   0.11E+26E+05

DECISION VARIABLES (X-VECTOR)
  11     0.75444E+00  0.11813E+01  0.75385E-01

CONSTRAINT VALUES (G-VECTOR)
  11    -0.53811E+00 -0.48185E+00 -0.13450E+02 -0.78555E+03 -0.29444E+00 -0.55610E-04
  21    -0.55491E-01 -0.17531E+00  0.58467E-02 -0.61652E-01  0.71621E-01 -0.12491E+00

THERE ARE     1 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
     6

THERE ARE     2 VIOLATED CONSTRAINTS
CONSTRAINT NUMBERS ARE
     9    11

THERE ARE     0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
     TEN CONSECUTIVE ITERATIONS FAILED TO PROVIDE A FEASIBLE DESIGN

NUMBER OF ITERATIONS =   10

OBJECTIVE FUNCTION WAS EVALUATED          37  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       37  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 2 FUNCTION VALUE 0.12863E+05

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	4	0.20000E+00	0.79444E+00	0.10000E+01
2	2	7	0.40000E+00	0.11813E+01	0.14000E+01
3	3	9	0.30000E-02	0.79389E-01	0.50000E+00

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.10000E+16	-0.51811E+00	0.0
2	12	-0.10000E+16	-0.48108E+00	0.0
3	13	-0.10000E+16	-0.13450E+02	0.0
4	14	-0.10000E+16	-0.58555E+03	0.0
5	15	-0.10000E+16	-0.25444E+00	0.0
6	16	-0.10000E+16	-0.55616E-02	0.0
7	17	-0.10000E+16	-0.55451E-01	0.0
8	18	-0.10000E+16	-0.17533E+00	0.0
9	19	-0.10000E+16	-0.58653E-02	0.0
10	20	-0.10000E+16	-0.41651E-01	0.0
11	21	-0.10000E+16	-0.71810E-01	0.0
12	22	-0.10000E+16	-0.12991E+00	0.0

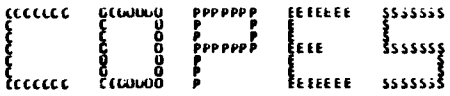
OPTIMIZATION RESULTS ------- DESIGN CASE NO. 3
SUBROUTINE "STRENA"

DESIGN VARIABLES SPECIFIED: PE,V,CS,N,DIA

ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	59.0000
	DENSITY (LBF-SEC**2/FT4)	=	1.9905
	VISCOSITY (FT2/SEC)	=	0.1281733046-04
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
HULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1725
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	0.0
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	0.0
	MATERIAL TYPE	=	STAINLESS STEEL
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTION VALUES:	PE (HP)	=	21292.6
	V (FT/SEC)	=	40.9171
	N (RPM)	=	105.0000
	QS (FT-LBF)	=	1200207.0
	PD (HP)	=	33030.05
	ETAC SPECIFIED	=	0.6527
	J	=	0.8290
	KT	=	0.2349
	KQ	=	0.0448
	ETAC	=	0.6913
	REY75R	=	0.3E+08
	DIA (FT)	=	22.0000
	P/C	=	1.1813
	AE/AC	=	0.7944
	T/C .75R	=	0.0754
	BLADE WEIGHT (LBF)	=	12842.6
CONSTRAINT VALUES:	MAX DIA (FT)	=	0.0
	MIN AE/AO	=	0.3515
	MIN T/C .75R	=	0.0690?6
PROPELLER "POINTS":	PE DEVELOPED (HP)	=	23168.1
	V (KNOTS)	=	24.2400
	QS REQUIRED (FT-LBF)	=	1408084.0
	N (RPM)	=	105.0000
	PD REQUIRED (HP)	=	26150.35

PROGRAM CALLS TO ANALYZ

ICALC	CALLS	*
1	1	
2	3	
3	2	



C E N T R O L P R O G R A M
F O R
E N G I N E E R I N G S Y N T H E S I S

T I T L E
WAGENINGEN B-SERIES PROPELLER OPTIMIZATION

```
CARD 1SPACES OF CONTROL DATA

CARD                    IMAGE

  1| $R  TITLE
  2|   'WAGENINGEN B-SERIES PROPELLER OPTIMIZATION
  3| $E     ACALC        NEV         NSV        MZVAR      MXAPRX      IPNPLT       IPUB
  4|                        3                                              0
  5| $C  IFRIN1      ITMAX      ICNDIR       NSCAL       ITKM      LINOBJ      NALMX
  6|                  1000                      -1         30
  7| $C1    FUCN      FDCHM          CT       CTMIN        CTL     CTLMIN        THCT
  8|         .001       .001        -.01
  9| $C2 DELFUN     DABFUN     ALPHAX     ABCOJI
 10|
 11| $E  NEVTOT       LOBJ     SGACPI
 12|          3          2       -1.0
 13| $F       VLB        VUB          X       SCAL
 14|         0.2          1.1       1.00        1.0
 15|         0.4          1.2          1        1.0
 16|       C.003          0.3  0.C130       0.100
 17| $G  NCSSGN      IDSGN      APULT
 18|          1          3        1.0
 19|          1          7        1.0
 20|          1          9        1.0
 21| $F    ACON
 22|          12
 23| $II     ICON       JCON       LCON
 24| $I2       BL      SCAL1         BU      SCAL2
 25|                      11
 26|  -1.0    +10         10        0.0        1.0
 27|                      12
 28|  -1.0    +10         12        0.0        1.0
 29|                      13
 30|  -1.0    +10         13        0.0        1.0
 31|                      14
 32|  -1.0    +10         14        0.0        1.0
 33|                      15
 34|  -1.0    +10         15        0.0        1.0
 35|                      16
 36|  -1.0    +10         16        0.0        1.0
 37|                      17
 38|  -1.0    +10         17        0.0        1.0
 39|                      18
 40|  -1.0    +10         18        0.0        1.0
 41|                      19
 42|  -1.0    +10         19        0.0        1.0
 43|                      20
 44|  -1.0    +10         20        0.0        1.0
 45|                      21
 46|  -1.0    +10         21        0.0        1.0
 47|                      22
 48|  -1.0    +10         22        0.0        1.0
 49| $S
 50| EOC
```

```
TITLE:
  WAGENINGEN B-SERIES PROPELLER OPTIMIZATION


CONTROL PARAMETERS:
CALCULATION CONTROL.                                  NCALC =    2
NUMBER OF GLOBAL DESIGN VARIABLES.                    NGV   =    3
NUMBER OF SENSITIVITY VARIABLES.                      NSV   =    0
NUMBER OF FUNCTIONS IN TLO-SPACE.                     NFVAR =    0
NUMBER OF APPROXIMATION VAR.                          NAPPR =    0
INPUT ALLOCATION PRINT CODE.                          IPALPU =   0
DEBUG PRINT CODE.                                     IPDBG =    0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TLO-VARIABLE CONSTANT SPACE
  5     CONSTRAIN SENSITIVITY
  6     APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION
GLOBAL VARIABLE NUMBER OF OBJECTIVE                   =  2
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION)          = -0.10000E+01
CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

 IPRINT     ITMAX     ICNDIR     NSCAL     LINOBJ     LINOBJ     NACMXI     NFDG
      1      1000          0        -1         50          0         15        0

 FDCH                 FDCHM                CT                   CTMIN
 0.10000E-02          0.10000E-02          -0.10000E-01         0.0

 CTL                  CTLMIN               THETA                PHI
 0.0                  0.0                  0.0                  0.0

 DELFUN               DABFUN               ALPHAX               ABOBJ1
 5.0                  0.0                  3.0                  3.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER              UPPER              INITIAL              SCALE
NO.        BOUND              BOUND              VALUE
  1    0.10000E+00        0.11000E+01        0.10000E+00        0.10000E+01
  2    0.10000E+00        0.15000E+01        0.12000E+01        0.10000E+01
  3    0.10000E-02        0.30000E+00        0.17000E-01        0.10000E+00

DESIGN VARIABLES
ID     D. V.     GLOBAL     MULTIPLYING
       NO.       VAR. NO.   FACTOR
  1       1          1      0.10000E+01
  2       2          2      0.10000E+01
  3       3          3      0.10000E+01

CONSTRAINT INFORMATION
THERE ARE 12 CONSTRAINT SETS
          GLOBAL     GLOBAL     LINEAR          LOWER          NORMALIZATION          UPPER
 ID       VAR. 1     VAR. 2     ID              BOUND          FACTOR                 BOUND
  1          11         11          0     -0.10000E+16     0.10000E+01          0.0
  2          12         12          0     -0.10000E+16     0.10000E+01          0.0
  3          13         13          0     -0.10000E+16     0.10000E+01          0.0
  4          14         14          0     -0.10000E+16     0.10000E+01          0.0
  5          15         15          0     -0.10000E+16     0.10000E+01          0.0
  6          16         16          0     -0.10000E+16     0.10000E+01          0.0
  7          17         17          0     -0.10000E+16     0.10000E+01          0.0
  8          18         18          0     -0.10000E+16     0.10000E+01          0.0
  9          19         19          0     -0.10000E+16     0.10000E+01          0.0
 10          20         20          0     -0.10000E+16     0.10000E+01          0.0
 11          21         21          0     -0.10000E+16     0.10000E+01          0.0
 12          22         22          0     -0.10000E+16     0.10000E+01          0.0

TOTAL NUMBER OF CONSTRAINED PARAMETERS =   12
```

OPTIMIZATION RESULTS -------	DESIGN CASE NO. 3 SUBROUTINE "STRIAK"		
DESIGN VARIABLES SPECIFIED:	PE,V,DS,N,DIA		
ENVIRONMENTAL PARAMETERS:	TEMP (DEG F)	=	55.0000
	DENSITY (LBF-SEC2/FT4)	=	1.9905
	VISCOSITY (FT2/SEC)	=	0.1411000046-5
	ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
	WATER VAPORIZATION PRESSURE (PSIA)	=	0.2470
NULL PARAMETERS:	WAKE FRACTION	=	0.2200
	THRUST DEDUCTION FRACTION	=	0.1100
	RELATIVE ROTATIVE EFFICIENCY	=	1.0250
	NUMBER OF PROPELLERS	=	1.0
	DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
	DIAMETER LIMIT (FT)	=	0.0
PROPELLER PARAMETERS:	NUMBER OF BLADES	=	6.0
	MATERIAL TYPE	=	STAINLESS STE
	ALLOWABLE STRESS (PSI)	=	5400.0
SELECTION VALUES:	PE (HP)	=	17630.0
	V (FT/SEC)	=	34.8255
	N (RPM)	=	175.0000
	QS (FT-LBF)	=	2.0264E7.0
	PD (HP)	=	30000.05
	ETAC SPECIFIED	=	0.5396
	J	=	0.7866
	KT	=	0.2212
	KQ	=	0.0638
	ETAO	=	0.8302
	AE/AO	=	0.6E+38
	DIA (FT)	=	21.0.000
	P/D	=	1.3000
	AE/AO	=	1.0000
	TC .75R	=	0.0100
	BLADE WEIGHT (LBF)	=	2563.1
CONSTRAINT VALUES:	MAX DIA (FT)	=	0.0
	MIN AE/AO	=	1.0700
	MIN TC .75R	=	0.258838
PROPELLER "PCINIS":	PE DEVELOPED (HP)	=	17514.5
	V (KNOTS)	=	23.0000
	QS REQUIRED (FT-LBF)	=	2.0+5969.0
	N (RPM)	=	183.3303
	PD REQUIRED (HP)	=	40076.84

```
        C C A N I N
   FORTRAN PROGRAM FOR
CONSTRAINED FUNCTION MINIMIZATION

INITIAL FUNCTION INFORMATION

OBJ =   0.256313E+04

DECISION VARIABLES (X-VECTOR)
  1)     0.11000E+01  0.13300E+01  0.10000E-01

CONSTRAINT VALUES (G-VECTOR)
  1)    -0.45100E+00 -0.50841E+00 -0.36545E+02 -0.96245E+03 -0.50100E+00  0.
  6)     0.98487E-02 -0.24471E+00 -0.56066E+00  0.33589E+00  0.90855E-01  0.
```

```
FINAL OPTIMIZATION INFORMATION

 OBJ =   0.164647E+05

 DECISION VARIABLES (X-VECTOR)
   1)      0.77419E+00  0.10906E+01  0.66118E-01

 CONSTRAINT VALUES (G-VECTOR)
   1)   -0.45160E+00 -0.50845E+00 -0.15063E+02 -0.98255E+03 -0.27419E+00 -0.
   7)   -0.46220E-01 -0.18658E+00 -0.24834E-02 -0.22189E+00 -0.25204E-32  0.

 THERE ARE    3 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
      6    11    12

 THERE ARE    0 VIOLATED CONSTRAINTS

 THERE ARE    0 ACTIVE SIDE CONSTRAINTS

 TERMINATION CRITERION
      ABS((OBJ(I-1)-OBJ(I))/OBJ(I)) LESS THAN DELFUN FOR 30 ITERATIONS
      ABS(OBJ(I)-OBJ(I-1))  LESS THAN DABFUN FOR 30 ITERATIONS

 NUMBER OF ITERATIONS =   46

 OBJECTIVE FUNCTION WAS EVALUATED          102  TIMES

 CONSTRAINT FUNCTIONS WERE EVALUATED       102  TIMES
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 2 FUNCTION VALUE 0.10465E+05

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	3	0.25000E-06	0.77419E+00	0.11000E+01
2	2	4	0.41000E-30	0.10906E+01	0.14000E+01
3	3	9	0.31000E-32	0.68118E-01	0.52000E+00

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	11	-0.11000E+16	-0.49160E+00	0.0
2	12	-0.11000E+16	-0.30842E+00	0.0
3	13	-0.11000E+16	-0.15063E+02	0.0
4	14	-0.11000E+16	-0.56356E+03	0.0
5	15	-0.11000E+16	-0.47416E+00	0.0
6	16	-0.11000E+16	-0.42822E-01	0.0
7	17	-0.11000E+16	-0.16558E+00	0.0
8	18	-0.11000E+16	-0.24834E-02	0.0
9	19	-0.11000E+16	-0.12185E+00	0.0
10	20	-0.11000E+16	-0.25206E-02	0.0
11	21	-0.11000E+16	0.86784E-04	0.0
12	22	-0.11000E+16	0.86784E-04	0.0

OPTIMIZATION RESULTS ------- DESIGN CASE NO. 3
SUBROUTINE "STRCNA"

DESIGN VARIABLES SPECIFIED: PE,V,NS,N,DIA

ENVIRONMENTAL PARAMETERS:

TEMP (DEG F)	=	55.0000
DENSITY (LBF-SEC2/FT4)	=	1.9905
VISCOSITY (FT2/SEC)	=	0.12817034E-0
ATMOSPHERIC PRESSURE (PSIA)	=	14.7000
WATER VAPORIZATION PRESSURE (PSIA)	=	0.2478

HULL PARAMETERS:

WAKE FRACTION	=	0.2200
THRUST DEDUCTION FRACTION	=	0.1313
RELATIVE ROTATIVE EFFICIENCY	=	1.0250
NUMBER OF PROPELLERS	=	1.0
DEPTH TO SHAFT CENTERLINE (FT)	=	15.0000
DIAMETER LIMIT (FT)	=	0.0

PROPELLER PARAMETERS:

NUMBER OF BLADES	=	4.0
MATERIAL TYPE	=	STAINLESS STE
ALLOWABLE STRESS (PSI)	=	5400.0

SELECTION VALUES:

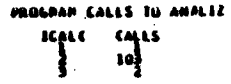
PE (HP)	=	17630.0
V (FT/SEC)	=	38.8240
N (RPM)	=	105.3000
QS (FT-LBF)	=	1500607.0
PD (HP)	=	33000.05
ETAC SPECIFIED	=	0.5394
J	=	0.7666
KT	=	0.2063
KQ	=	0.0372
ETAC	=	0.6950
REYN75R	=	0.3E+08
DIA (FT)	=	22.0000
P/D	=	1.0500
AE/AO	=	0.7742
T/C .75R	=	0.0681
BLADE WEIGHT (LBF)	=	1C464.7

CONSTRAINT VALUES:

MAX DIA (FT)	=	0.0
MIN AE/AO	=	0.7722
MIN T/C .75R	=	0.068124

PROPELLER "POINTS":

PE DEVELOPED (HP)	=	17673.8
V (KNOTS)	=	23.0000
QS REQUIRED (FT-LBF)	=	1167640.0
N (RPM)	=	105.0000
PD REQUIRED (HP)	=	23343.40


PROGRAM CALLS TO ANALIZ
SCALE
CALLS
5
10

LIST OF REFERENCES

1. van Lameren, W.P.A., van Manen, J.D. and Oosterweld, M.W.C., "The Wageningen B-Screw Series", Transactions S.N.A.M.E., v. 77, p. 269-317, 1969.

2. Oosterweld, M.W.C. and van Oossanen, P., "Further Computer-Analyzed Data of the Wageningen B-Screw Series", International Shipbuilding Progress, v. 22, no. 251, p. 251-262, July 1975.

3. Triantafyllou, M.S., "Computer-Aided Propeller Preliminary Design Using the B-Series", Marine Technology, v. 16, no. 4, p. 381-391, October 1979.

4. Markussen, P.A., "On the Optimum Wageningen B-Series Propeller Problem with Cavitation-Limiting Restraint", Journal of Ship Research, v. 23, no. 2, p. 108-114, June 1979.

5. NASA Ames Research Center Technical Memorandum NASA TMX-62 282, CONMIN--A FORTRAN Program for Constraint Minimization User's Manual, by G.N. Vanderplaats, August 1973.

6. Vanderplaats, G.N., CONMIN User's Manual Addendum, May 1978.

7. Naval Postgraduate School Publication NPS69-81-003, COPES--A FORTRAN Control Program for Engineering Synthesis, by L.E. Madsen and G.N. Vanderplaats, March 1982.

8. Schoenherr, K.E., "Formulation of Propeller Blade Strength", Transactions S.N.A.M.E., v. 71, p. 81-119, 1963.

9. Fox, R.L., Optimization Methods for Engineering Design, Addison-Wesley Publishing Company, 1971.

10. Fiacco, A.V. and McCormick, G.P., Non-Linear Programming: Sequential Unconstrained Minimization Techniques, John Wiley and Sons, 1969.

11. Himmelblau, D.M., Applied Non-Linear Programming, McGraw Hill Company, 1972.

12. Vanderplaats, G.N., "Structural Optimization--Past, Present and Future", AIAA Journal, v. 20, no. 7, p. 992-1000, July 1982.

13. Fletcher, R. and Reeves, C.M., "Function Minimization by Conjugate Directions", Computer Journal, v. 7, no. 2, p. 149-154, 1964.

14. Zoutendijk, G.G., Methods of Feasible Directions, Elsevier Publishing Co., 1960.

15. Vanderplaats, G.N. and Moses, F., "Structural Optimization by Methods of Feasible Directions", Journal of Computers and Structures, v. 3, p. 739-755, 1973.

16. Comstock, J.P. (Ed.), Principles of Naval Architecture, The Society of Naval Architects & Marine Engineers, 1967.

17. O'Brien, T.P., The Design of Marine Screw Propellers, Hutchinson and Company, Ltd. (UK), 1962.

18. Vassilopoulos, L., "Formulation and Computer-Aided Solution of a Class of Propeller Design Problems", International Shipbuilding Progress, v. 23, no. 257, p. 10-29, January 1976.

19. Netherlands Ship Model Basin Report 132a, Fundamentals of Ship Resistance and Propulsion Part B: Propulsion, by Dr. Ir. J.D. van Manen, 1955.

20. Lerbs, H.W., "On the Scale and Roughness of Free Running Propellers", Journal of the American Society of Naval Engineers, v. 63, no. 1, p. 58-94, 1952.

21. Triantafyllou, M.S., Development of Analytical Methods in the B-Series Propeller Design for Application in Computer Programs, S.M. Thesis, Massachusetts Institute of Technology, Cambridge, 1977.

22. Taylor, D.W., The Speed and Power of Ships: A Manual for Marine Propulsion, Randsdell, Inc., 1933.

23. Rosingh, W.H.C.E., "Design and Strength Calculation for Heavily Loaded Propellers", Schip en Werf, 1937.

24. Hancock, N., "Blade Thickness of Wide-Bladed Propellers", Transactions R.I.N.A., v. 83, 1942.

25. Romson, J., "Propeller Strength Calculation", The Marine Engineer and Naval Architect, n. 2-3, 1952.

26. David W. Taylor Model Basin, Report 919, An Approximate Method of Obtaining Stress in a Propeller Blade, by W.B. Morgan, October 1954.

27. Arnoldus, W. and Keyser, R., "Strength Calculation of Marine Propellers", International Shipbuilding Progress, v. 6, no. 53, p. 20-36, January 1959.

28. Conn, J.F.C., "Marine Propeller Blade Deflection", Transactions R.I.N.A., 1943.

29. Netherlands Research Center TNO for Shipbuilding and Navigation, Deflt, Report 21S, On Stress Calculations in Hellicoidal Shells and Propeller Blades, by J.W. Cohen, July 1955.

30. Connolly, J.E., "Strength of Propellers", Transactions R.I.N.A., v. 103, no. 2, p. 139-160, April 1961.

31. General Applied Science Laboratory, Inc., Report 283, Propeller Blade Vibration and Stress Analysis Program, by E. Lieberman, June 1963.

32. General Applied Science Laboratory, Inc., Report 466, Extension of Propeller Blade Stress Program, by E. Lieberman, 1964.

33. Atkinson, P., "On the Choice of Method for Calculation of Stress in Marine Propellers", Transactions R.I.N.A., v. 110, no. 4, p. 447-463, October 1968.

34. Sontvedt, Terje, "Propeller Blade Stresses--An Application of Finite Element Methods", Computers and Structures, v. 4, no. 1, p. 193-204, January 1974.

35. Naval Ship Research and Development Center Department of Structural Mechanics Research & Development, Report 3397, Elastic Strength of Propellers--An Analysis by Matrix Methods (Including a Programmer's Manual and a User's Manual), by Paris Genalis, July 1970.

36. Hamilton Standard Company, A Division of United Technologies, Final Technical Report, HS-01-033072, Expanded Computer Program for Structural Analysis of Marine Propellers, by W.W. Westervelt and A.S. Dale, December 1972.

37. Atkinson, P., "Prediction of Marine Propeller Distortion and Stresses Using a Super-Parametric Thick-Shell Finite Element Model", Transactions R.I.N.A.--Supplementary Papers, v. 115, p. 359-375, November 1973.

38. Araldsen, P.O. and Egeland, O., "General Description of SESAM-69 (Super Element Analysis Modules", European Shipbuilding, v. 2, 1971.

39. Atkinson, P., A Practical Stress Analysis Procedure for Marine Propellers Using Curved Finite Elements, paper presented at S.N.A.M.E. Propellers '75 Symposium, 6th, Philadelphia, Pennsylvania, July 1975.

40. Ma, J.H., Schnobrick, W.C. and Stuber, C.B., Propeller Stress Calculation Using Curved Finite Elements, paper presented at S.N.A.M.E. Propellers '75 Symposium, 1st, Philadelphia, Pennsylvania, July 1975.

41. Beek, G.H.M., "Calculation of Propeller Blade Streses and Comparison with Test Results", International Shipbuilding Progress, v. 24, no. 277, p. 225-236, September 1977.

42. Beek, G.H.M., Hub-Blade Interaction in Propeller Strength, paper presented at S.N.A.M.E. Propellers '78 Symposium, 19th, Virginia Beach, Virginia, 25 May 1978.

43. Naval Ship Research and Development Center Structures Department Research and Development Report, DTNSRDC-78/016, Curved Finite Elements Computer Program--PBLADE User's Manual, by J.H. Ma, April 1978.

44. Naval Ship Research and Development Center Structures Department Research and Development Report, No. 4057, Stress Analysis of Complex Components by a Numerical Procedure Using Curved Finite Elements, by J.H. Ma, July 1973.

45. David W. Taylor Naval Ship Research and Development Center Ship Performance Department Report, SPD-595-01, A Lifting Line Computer Program for Preliminary Design of Propellers, by J.A. Diskin and T.A. LaFone, November 1975.

46. Saunders, H.E., Hydrodynamics in Ship Design, Volume II, The Society of Naval Architects and Marine Engineers, 1957.

47. Vanderplaats, G.N., Sugimoto, H. and Sprague, C.M., "ADS-1 A New General Purpose Optimization Algorithm", Proceedings 24th AIAA/ASME/ASCE/AHS S-ructures, Structural Dynamics and Materials Conference, Lake Tahoe, Nevada, May 1983.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 69Mx Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	1
4.	Professor G.N. Vanderplaats, Code 69Vn Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	3
5.	LCDR Michael R. Maixner, Code 69Mq Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	2
6.	LT Michael P. Smith II, USNR c/o Mr. & Mrs. Michael P. Smith 12 Linmouth Road Malverne, New York 11565	4
7.	Professor Michael G. Parsons Chairman Department of Naval Architecture & Marine Engineering The University of Michigan Ann Arbor, Michigan 48109	2
8.	Professor T. Francis Ogilvie Chairman Department of Ocean Engineering Room 5-225 The Massachusetts Institute of Technology Cambridge, Massachusetts 02139	2
9.	Professor Michael S. Triantafyllou Department of Ocean Engineering, Room 5-225 The Massachusetts Institute of Technology Cambridge, Massachusetts 02139	1

10. Dr. William B. Morgan — 1
David W. Taylor Naval Ship Research
& Development Center
Ship Performance Department (Code 15)
Bethesda, Maryland 20084

11. Dr. Young T. Shen — 1
David W. Taylor Naval Ship Research
& Development Center
Ship Performance Department
Bethesda, Maryland 20084

12. Commander (NAVSEA-52) — 1
ATTN: CAPT G.M. LaChance
Naval Sea Systems Command
Washington, D.C. 20362

13. Commander (NAVSEA-3213) — 1
ATTN: Mr. David Byers
Naval Sea Systems Command
Washington, D.C. 20362

14. Commander (NAVSEA-312) — 1
ATTN: Mr. S.F. "Frank" Burkeen
Naval Sea Systems Command
Washington, D.C. 20362

15. Mr. Andy Szypula — 1
SNAME Headquarters
One World Trade Center, Suite 1369
New York, New York 10048

16. Technical Library (Code 522.1) — 1
David W. Taylor Naval Ship Research
& Development Center
Bethesda, Maryland 20084

17. Technical Library — 1
David W. Taylor Naval Ship Research
& Development Center
Annapolis, Maryland 21402

18. Commander (NAVSEA-99612) — 1
ATTN: Library/D.R. Erickson
Naval Sea Systems Command
Washington, D.C. 20362

19. Librarian — 1
Department of Naval Architecture
& Offshore Engineering
The University of California
Berkeley, California 94720

END

DATE
FILMED

9 83

DTIC